PB81-248122

Full-Scale Demonstration of Industrial Wastewater Treatment Utilizing Du Pont's PACT (Trade Name) Process

E. I. Du Pont de Nemours and Co.
Deepwater, NJ

Prepared for

Robert S. Kerr Environmental Research Lab.
Ada, OK

Sep 81

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA-600/2-81-159
September 1981

PB81-248122

FULL-SCALE DEMONSTRATION OF INDUSTRIAL WASTEWATER TREATMENT UTILIZING DU PONT'S PACT® PROCESS

(NOVEMBER, 1976, THROUGH DECEMBER, 1979)

by

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1. REPORT NO. EPA-600/2-81-159	2. ORD Report	3. RECIPIENT'S ACCESSION NO. PB81 248122
4. TITLE AND SUBTITLE Full-scale Demonstration of Industrial Wastewater Treatment Utilizing du Pont's PACT^R Process (November, 1976, through December, 1979)		5. REPORT DATE September 1981 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Harry W. Heath, Jr.		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS E. I. du Pont de Nemours & Co., Inc. Chambers Works Deepwater, NJ 08023		10. PROGRAM ELEMENT NO. CBGB1C 11. ~~CONTRACT/~~GRANT NO. S-804943
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Robt. S. Kerr Environmental Research Laboratory P. O. Box 1198 Ada, Oklahoma 74820		13. TYPE OF REPORT AND PERIOD COVERED Final/11-2-76 to 11-1-79 14. SPONSORING AGENCY CODE 600/15

15. SUPPLEMENTARY NOTES

16. ABSTRACT -- Operating and cost data on startup and the initial 30 months of operation of a 150,000 m^3/day (40-MGD) industrial wastewater treatment plant using Du Pont's PACT® process are reported. The process effectively provides secondary/tertiary treatment by adding powdered activated carbon to the aerator in an activated sludge process.

Removals of BOD_5 and color were 96% and 68%, respectively, exceeding expectations. Removal of Dissolved Organic Carbon (DOC) was 82%, approximately equal design. Removals were consistent even though the waste contained many relatively toxic, non-biodegradable organics and varied drastically in composition. A synergistic enhancement of biological activity in the presence of activated carbon was observed.

Operation at over 25 days sludge age reduced the required carbon dose from more than 170 mg/liter to 120 mg/liter. Activated carbon was regenerated in a multiple-hearth furnace. At 80% yield with recovery of 63% of virgin carbon properties, production rate and quality recovery were below expectations. Performance was hurt by underdesigned filtration and solids conveying equipment which limited throughput and in-time.

Excluding depreciation, operating costs for secondary/tertiary treatment alone have averaged \$0.16/m^3 (\$0.61/1,000 gal.). Including depreciation, costs have averaged \$0.33/m^3 (\$1.27/1,000 gal.).

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Powdered Activated Carbon Industrial Waste Treatment Organic Chemical Plants	Carbon Regeneration Operating Data Economics	68D

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 164
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized. EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate, and management of pollutants in ground water; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control, or abate pollution from the petroleum refining and petrochemical industries, and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report presents operating data on the start-up and initial 30 months of operation of an industrial wastewater treatment plant using Du Pont's patented PACT process. This industrial study has demonstrated PACT to be an effective method of treatment for complex organic chemical wastewaters.

Clinton W. Hall

Clinton W. Hall
Director
Robert S. Kerr Environmental Research Laboratory

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ABBREVIATIONS AND SYMBOLS

AE	Aerator
ATP	Adenosin tri-phosphate
BOD	Biological oxygen demand
^oC	Degrees, Centigrade
$CaCO_3$	Calcium carbonate
CF	Clarifier
cm	Centimeter
CO	Carbon monoxide
CY	Conveyor
D.F.	Number of degrees of freedom
DO	Dissolved oxygen
DOC	Dissolved organic carbon
E-BOD	Electrolytic biochemical oxygen demand
FP	Filter Press
ft^2	Square feet
gal.	Gallon
GC/MS	Gas chromatography/ mass spectrometer
gpm	Gallons per minute
H_2	Hydrogen
HCl	Hydrochloric acid
IN	Iodine number - a measure of iodine adsorption from solution
kg	Kilogram
lbs.	Pounds
σ	Standard Deviation
m	Meter
M	Thousand
m^2	Square meter
m^3	Cubic meter
mg	Milligram
MGD	Million gallons per day
min.	Minute
MLSS	Mixed liquor suspended solids
MM	Million
ug/l.	Micrograms/liter
N	No. of data points
NPDES	National Pollution Discharge Elimination System
O_2	Oxygen
PACT	Acronym for Powdered Activated Carbon Treatment
ppb	Parts per billion
RAS	Recycle Activated Sludge
S.D.	Standard deviation
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
WAO	Wet Air Oxidation
wt.	Weight
WWTP	Chambers Works Wastewater Treatment Plant
yd^3	Cubic yard

SECTION 1

INTRODUCTION

PROJECT CONCEPTION

This project was proposed to the U. S. Environmental Protection Agency (EPA) in April, 1976. Start up was imminent for secondary/tertiary ($2^o/3^o$) treatment facilities at a 150,000 m^3/min. (40 MGD) industrial wastewater treatment plant (WWTP) using Du Pont's patented* PACT process. This was to be the largest scale use to date of this novel treatment technology. It was suggested to EPA that this presented a unique opportunity to obtain actual operating data from a PACT plant. PACT is a combined activated sludge/activated carbon treatment which is achieved by adding powdered activated carbon directly to the aerator in a conventional activated sludge process. PACT promised tertiary treatment quality effluent for a cost only slightly higher than for activated sludge treatment alone.

In November of 1976, Du Pont and EPA agreed on a program, to be partially funded by EPA, to obtain detailed operating and cost data from the start-up and initial two years of full scale operation of this plant. This report concludes that study.

The facilities to be studied would be located at Du Pont's Chambers Works site at Deepwater, NJ. This WWTP would provide primary and secondary/tertiary treatment for aqueous waste from the Chambers Works and Du Pont's adjacent Carney's Point plant. Total investment for the WWTP was approximately $46,000,000. The primary treatment section of the WWTP was in full operation by 1976. Start up of the PACT portion of the plant began in November, 1976.

The Chambers Works is a large, multi-product, chemical plant manufacturing "Freon" fluorocarbons; general organic intermediates, mainly substituted aromatic compounds; dyes and dye intermediates; petroleum additives; isocyanates and elastomeric products; general industrial chemicals, particularly paper and textile treating chemicals; sulfuric acid; and miscellaneous other products. The wastewater from the plant is highly colored. Since most of the plant processes are batch, the wastewater periodically contains slug discharges of organics which results in a highly variable organic load, both in terms of dissolved organic carbon (DOC) concentration and concentration of specific organic compounds. Over 90% of the load to the WWTP is generated from Chambers Works production activities. Carney's Point was a nitrocellulose plant which generated an alcohol containing waste. That plant site was closed in 1979.

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* U.S. Patent Nos.: 4,069,148, and 3,904,518.

Chambers Works waste is strongly acidic, containing from 70,000 to 230,000 kg./day acid, expressed as $CaCO_3$ equivalent. During primary treatment the acid is neutralized with lime. Heavy metals are removed to varying degrees during the neutralization. The sludge formed is settled in primary clarifiers, filtered to give an approximately 50% solids cake, and disposed of in an on site, double lined, secure landfill. Clear, colored effluent from primary treatment has a pH between 6.0 and 8.0 and is the feed to the PACT process. Table 1 shows the composition of the wastewater fed to the PACT process during 1978 and 1979.

TABLE 1. AVERAGE FEED TO SECONDARY/TERTIARY (PACT) TREATMENT

	24 Months, Jan.'78 thru Dec. '79	Design Flowsheet
Avg. Flow Rate, m^3/min.	94.2 (24,900 gpm)	100 (26,400 gpm)
Soluble BOD_5, mg/liter	171	280
kg/day at average flow	23,200 (51,000 lbs./day)	40,300 (88,700 lbs./day)
DOC, mg/liter	170	205
kg/day at average flow	23,100 (50,800 lbs./day)	29,500 (65,000 lbs./day)
Color, APHA	1530	1000
pH	6.0-8.0	6.0-8.0
TSS, mg/liter	37	30
Total Dissolved Solids, mg/liter	2,000 to 5,000*	

*Not routinely determined, very few values available.

PACT DEVELOPMENT & COMPARISON WITH ACTIVATED SLUDGE PROCESS

The PACT process was developed as a result of technical studies of alternative treatment procedures for Chambers Works wastewater. Early work was concentrated in two areas, attempts to make a biological process work and physical-chemical methods.

Results of the studies can be generalized by saying the biological treatment process appeared most economical, but could not consistently meet the BOD limit; while physical-chemical treatments were expensive and failed to remove more than 60% BOD. Physical-chemical methods studied included chemical oxidation, adsorption, foam fractionation, solvent extraction, and permeation techniques.

The physical-chemical methods generally failed to remove those simple organic molecules, such as methanol and acetic acid, which were most easily bio-degraded. The biological units failed to remove some of the more complex organics, including those coloring the wastes strongly, and were plagued by periodic upsets. These upsets were caused by variations in total organic load as well as surges of specific toxic compounds. Secondary effects of these upsets included loss of bacterial solids in overflow from the secondary clarifier. Equalization of wastes prior to biological treatment did not alleviate these problems.

In an experiment, powdered activated carbon was added to a biological reactor. The results, with what became the first PACT reactor, were so immediately favorable that an active program was established to pursue this new technology.

Table 2 summarizes a set of typical laboratory operating data, obtained about the time of plant construction, which compares a PACT unit with a conventional activated sludge (biological) unit. Differences in color, DOC, and BOD removals achieved with the two processes are shown. Since waste treatment plants must meet limits on daily values as well as monthly averages, the spread of effluent values around an average must be considered in evaluating a process. Figure 1 shows such data. The more narrow spread of PACT effluent DOC values shows the effect of carbon protection of the bacteria from shock load upsets. The carbon provides an adsorption sink to minimize the effect of sudden organic concentration changes, thereby decreasing the number and duration of excursions of effluent DOC.

TABLE 2. TYPICAL LABORATORY "PACT" UNIT PERFORMANCE①

( ) = Standard Deviation

	PACT Unit	Biological Unit
Feed to Units		
Color, APHA Units		1690 (690)
DOC, mg/liter		171 (28)
BOD_5, mg/liter		300 (21)
Treated Effluent		
Color, APHA Units	310	1020
DOC, mg/liter	26 (13)	57 (27)
BOD_5, mg/liter	23 ②	38 ②
Operating Conditions		
Sludge Age, Days	8.0	8.3
Carbon Dose, mg/liter	160	0
Temperature, °C	15-24	15-24
Aerator Hydraulic Residence Time, Hrs.	6.1	5.7

① Data from time period, Oct. 1975-April 1976. Values are averages of 100 daily data points except for BOD.

② Averages of 36 data points. Eliminating 5 days of very high BOD on the bio-unit gives averages of 15 mg/liter and 20 mg/liter for PACT and bio unit respectively.

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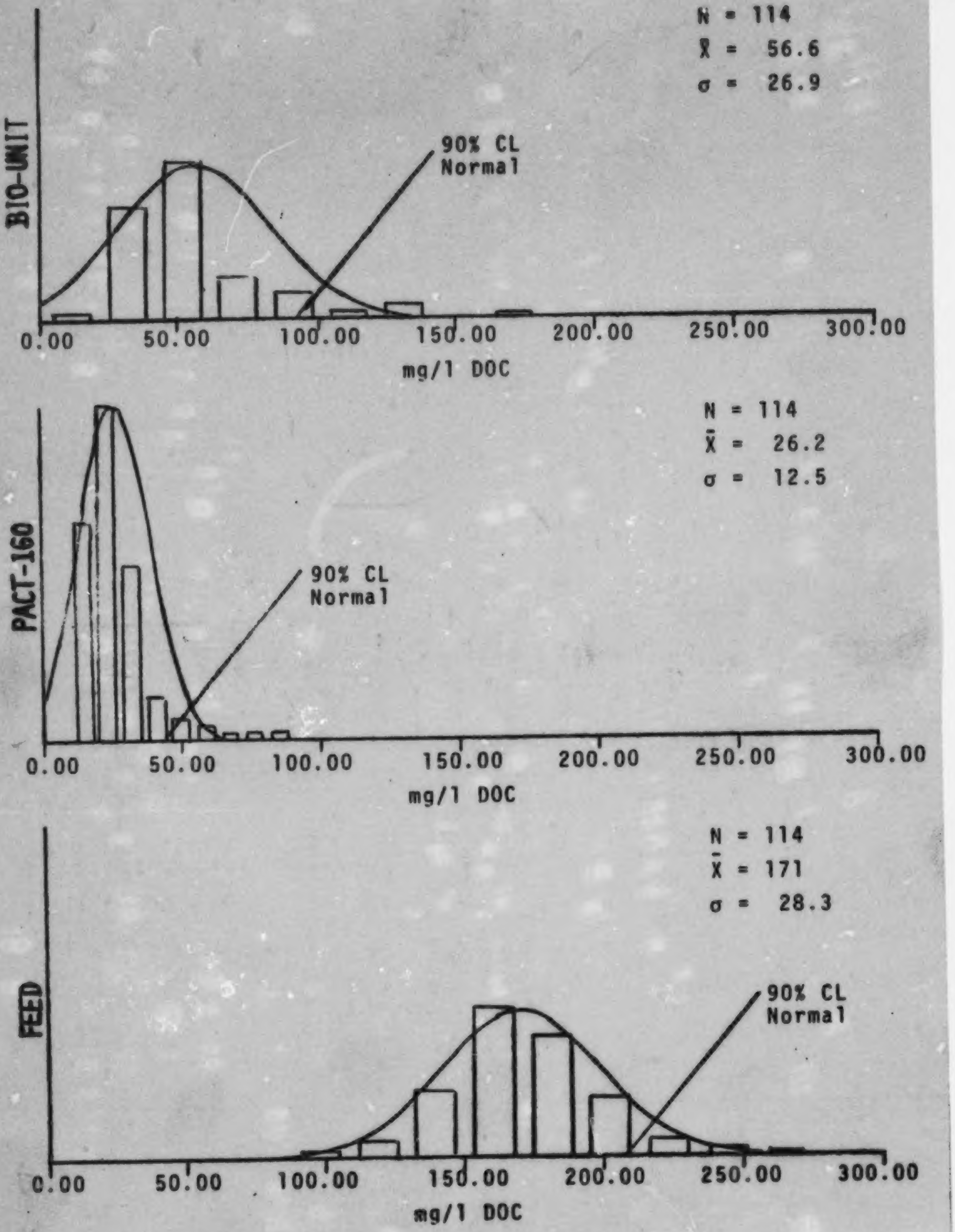

Figure 1. Histogram of feed and effluent DOC.

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There is synergism between the bacteria and carbon such that more organics become biodegradable in the presence of carbon. Table 3 shows the DOC removed from the effluent from a biological unit by carbon adsorption. The same activated carbon combined with bacteria in the PACT unit removed more DOC. The improvement in DOC removal with carbon in a PACT system is greater than would be expected from carbon adsorption isotherm data (Ref. 1).

TABLE 3. SYNERGISTIC EFFECT ON DOC REMOVAL WITH PACT

	DOC, mg/liter			
Date	Feed To Units	Bio Unit Effluent	Bio Unit Effluent + Batch Carbon Adsorption(1)	PACT(2) Effluent
09/15/76	183	80	59	44
10/26/76	178	70	40	18
11/22/76	167	79	55	25

(1) Take 500 cc filtered bio-unit effluent, add 150 ppm virgin carbon, stir 3 hours at room temperature, filter and analyze filtrate for DOC.

(2) PACT unit operating at 20°C with 8.0 day sludge age and 160 ppm carbon addition.

There are further improvements in system operation with PACT. The carbon in the aerator reduces foaming, which sometimes is a problem in a conventional activated sludge aerator. Since the PACT unit mixed liquor suspended solids (MLSS) contain a large fraction of carbon, the settling and filtration properties of the sludge are greatly improved. Figures 2 and 3 (Ref. 2) show typical, comparative settling and filtration data respectively for PACT vs. conventional biological sludge. These improved sludge handling properties have important economic ramifications in plant design.

In general, common operating variables affect a PACT system similarly to the way they would affect a conventional activated sludge system. However, the effect of carbon dosage is a function of the particular carbon used and the specific waste being treated. Figure 4 (Ref. 2) is a typical example of the response of Chambers Works waste to varying carbon dose.

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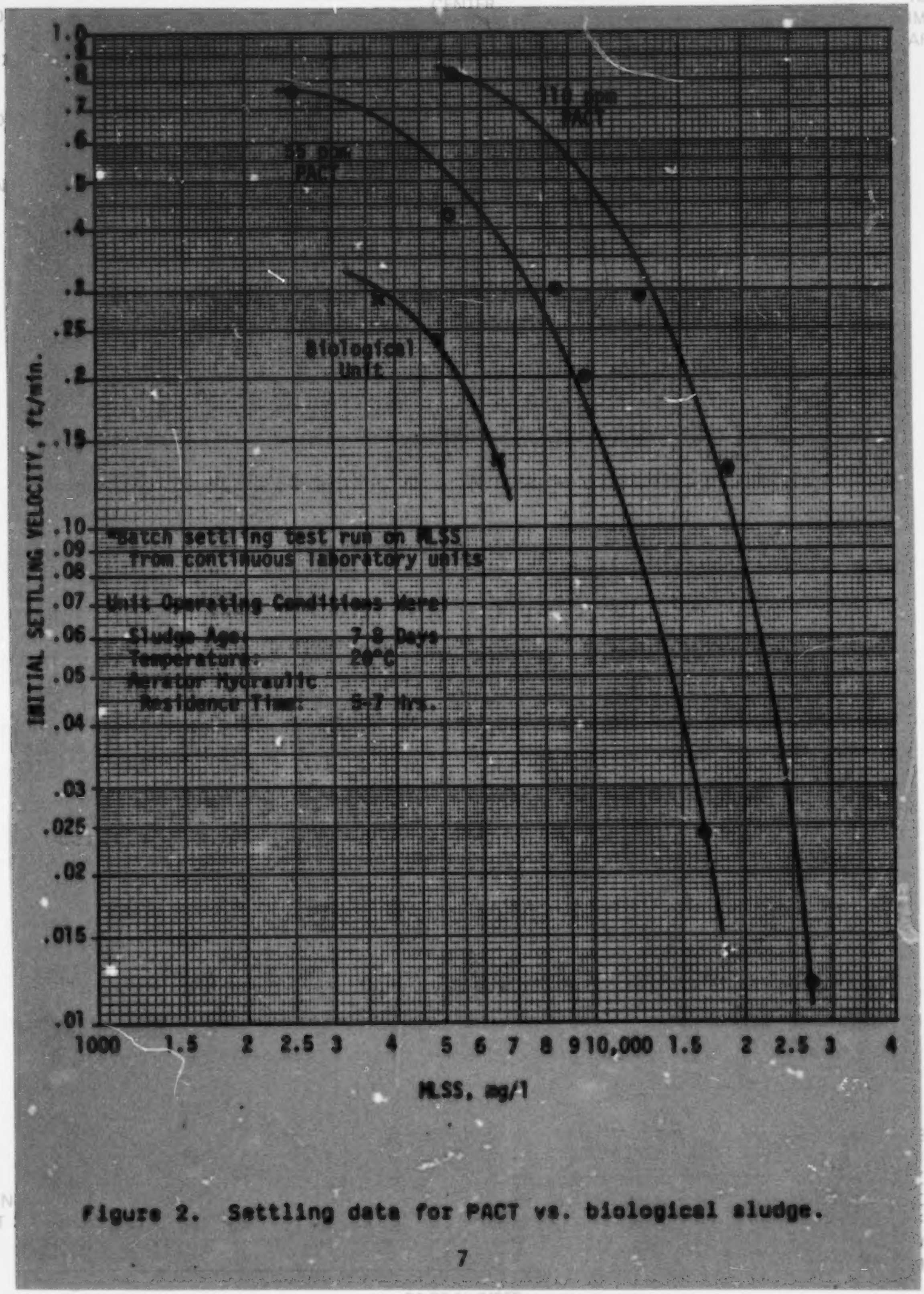

*Batch settling test run on MLSS from continuous laboratory units

Unit Operating Conditions Were:

Sludge Age: 7.8 Days
Temperature: 20°C
Aerator Hydraulic Residence Time: 5-7 Hrs.

Figure 2. Settling data for PACT vs. biological sludge.

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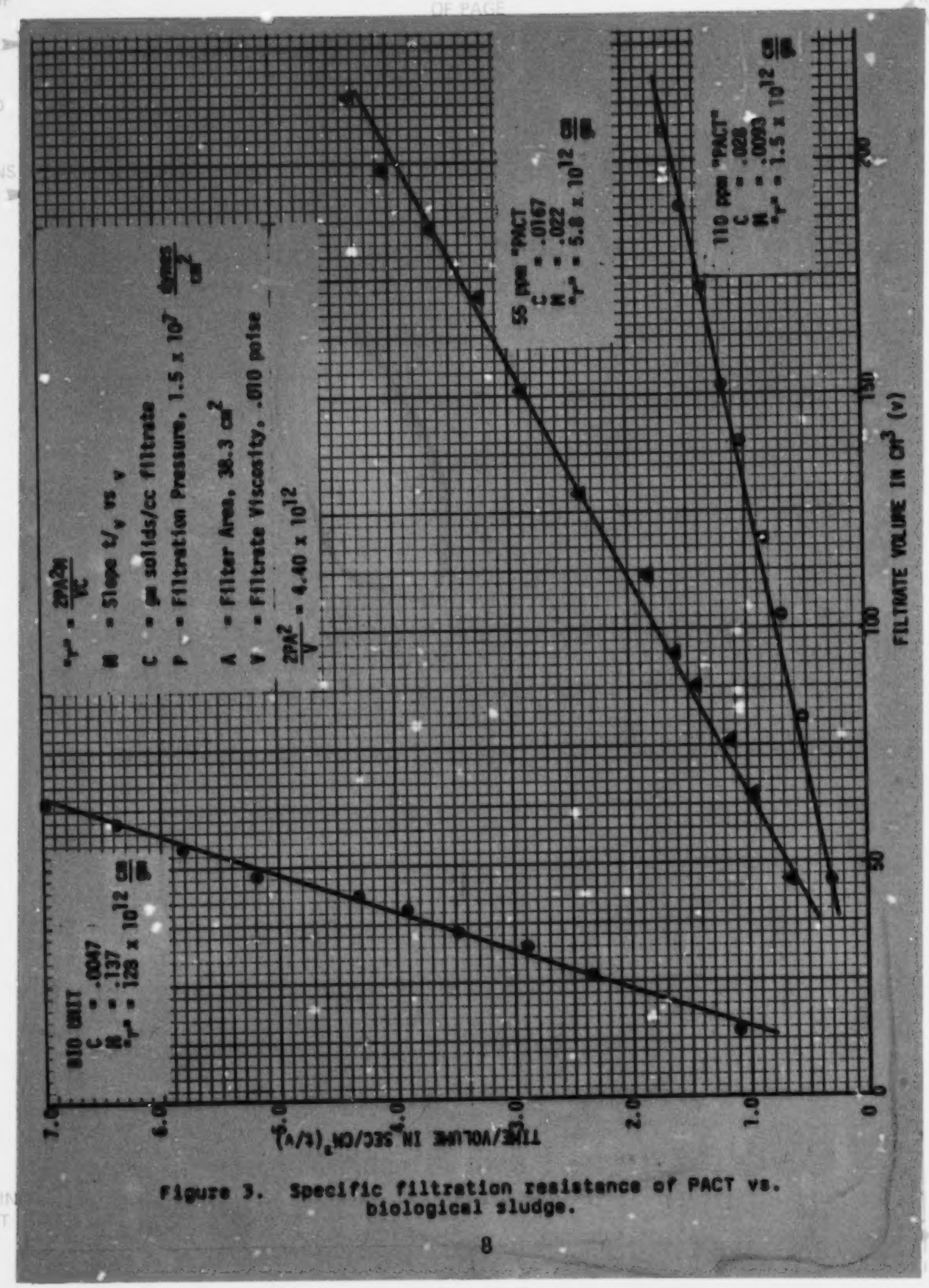

Figure 3. Specific filtration resistance of PACT vs. biological sludge.

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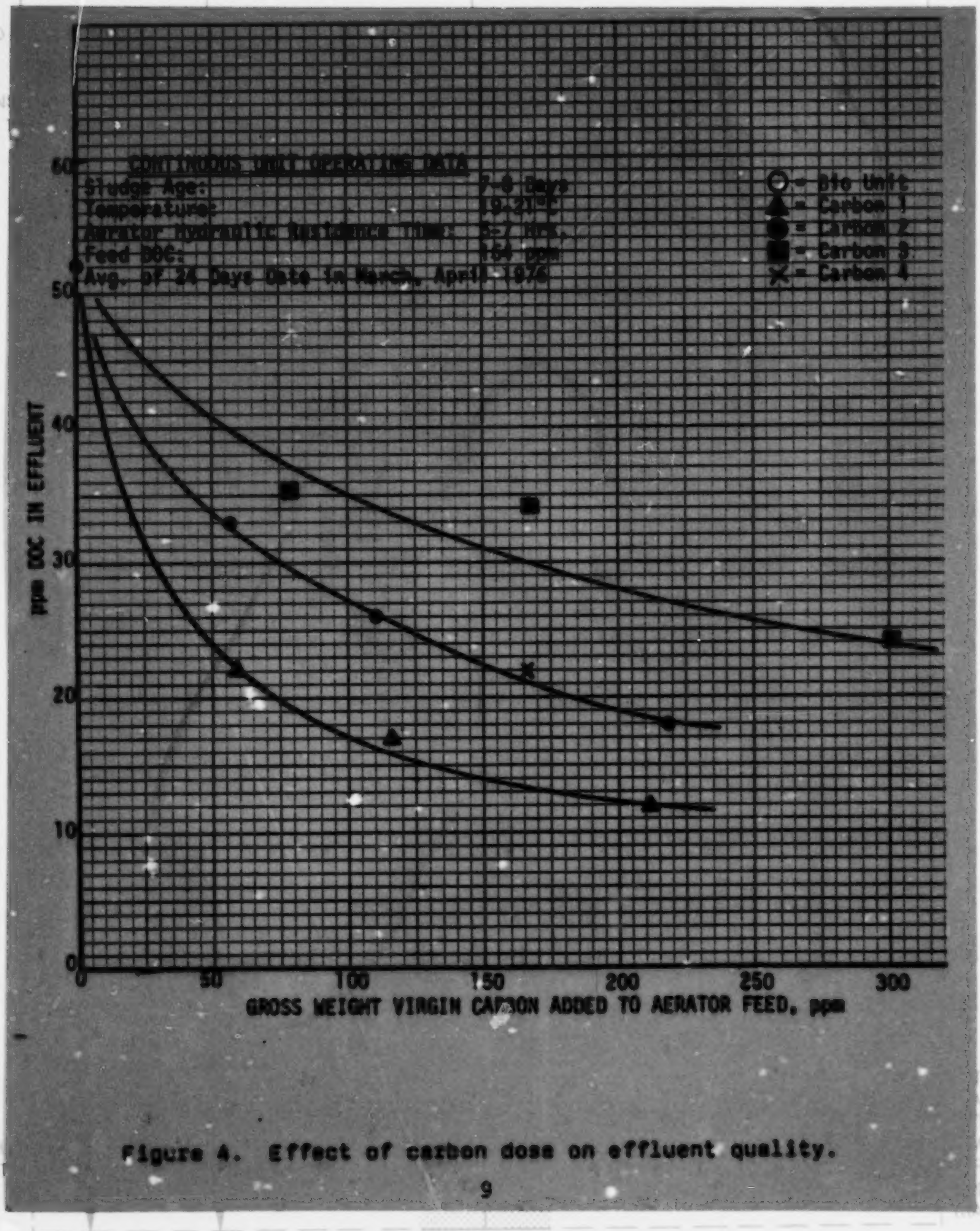

Figure 4. Effect of carbon dose on effluent quality.

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The laboratory studies with Chambers Works wastewater demonstrated that compared to a conventional activated sludge system at equal sludge age, eight days, the PACT process with 160 ppm carbon addition of one type carbon:

- gave consistent BOD removal of over 90%,
- raised DOC removal from 67% to 85%,
- reduced color,
- eliminated foaming in the aerator,
- improved sludge settling and filtration properties, and
- protected the micro-organisms from periodic shock loads of organics including toxic compounds.

SELECTION OF PACT FOR CHAMBERS WORKS - TECHNICAL AND ECONOMIC CONSIDERATIONS

By 1970 it became obvious that proposed regulatory limits on DOC and color would eliminate any chance that secondary treatment alone, even if it could be made to work, would be adequate for Chambers Works waste. Recognizing that some form of tertiary treatment would be required, an extensive review of available technology was made. The most promising alternate to PACT appeared to be granular carbon columns located either before or after a conventional biological reactor. These options were studies in detail vs. PACT (Ref. 3).

Neither combination of carbon columns with a biological unit performed as well as PACT. With the carbon column after the biological reactor, the reactor was frequently upset by shock loads of organics. The use of carbon columns before the biological unit was inefficient because comparatively expensive carbon adsorption capacity was occupied by biodegradable compounds. Also, the changing composition of wastewater produced a chromatographic effect in column effluent, such that the biological unit after the carbon column did not receive protection from shock loads.

Investment costs for the PACT system were lower than for either of the carbon column systems. Very generally, the investment difference was caused by the added expense for: 1) separate carbon columns, as opposed to containing the carbon in the PACT aerator; and 2) a not so immediately obvious expense for twice the clarification capacity in the biological portion of carbon column systems. The superior settling properties of PACT sludge vs. solely biological sludge resulted in much less clarifier capacity being required with the PACT system.

During initial PACT work powdered activated carbon was relatively inexpensive. As plans for a PACT plant progressed the cost of suitable commercial powdered carbons increased by three to four times. Considering that at the proposed 170 mg/liter carbon dosage the Chambers Works treatment plant would consume almost 9 million kg./year powdered carbon on a once-through basis, the attractiveness of carbon regeneration became obvious. Beyond purchased carbon savings, a regeneration furnace also serves as an incinerator for biological solids. This solves a major and increasingly costly sludge disposal problem faced by conventional activated sludge plants.

A multiple hearth regeneration furnace was selected for the Chambers Works plant. As this was to be the largest scale use to date of this type of equipment for powdered carbon regeneration, pilot scale tests were made. The greatest concern with the multiple hearth furnace was whether countercurrent gas flow up the furnaces could be controlled to avoid blowing all the carbon out the top and still provide good regeneration. Tests showed it was possible.

A further concern, independent of thermal regeneration equipment type, was whether inorganic salts would accumulate on the carbon with successive regenerations. It was postulated they might cause fusing on the carbon at regeneration temperatures and block off active surface area. While there was an increase in ash content after regeneration, this ash was easily removed by a dilute hydrochloric acid wash. The regenerated, acid washed carbon performed satisfactorily in laboratory PACT units. In the Chambers Works plant the acid washings are recycled to primary treatment. The dissolved inorganics precipitate during lime neutralization and are purged from the system with unreacted lime sludge.

PACT process economics were compared with a conventional activated sludge process for the Chambers Works, even though the latter was not a viable alternate in this case. Cost estimates for PACT secondary/tertiary treatment vs. secondary treatment by a conventional activated sludge plant were within 10% of each other. The extra PACT investment for carbon handling and regeneration facilities was mostly offset by the additional clarifier capacity and sludge disposal facility needed for the activated sludge plant. Assuming a 75% regeneration yield for powdered carbon, operating costs for the PACT process were about 25% greater than activated sludge alone. In effect the PACT process at Chambers Works was expected to provide tertiary treatment quality effluent at a cost close to that for secondary treatment alone. In one piece of equipment, the aerator, the PACT process permits most of the organic wastes to be destroyed relatively cheaply by biological action, while using expensive carbon efficiently to remove only difficultly biodegradable or normally non-biodegradable substances.

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SECTION 2

CONCLUSIONS

1. PACT IS AN ideal advanced wastewater treatment process for industrial wastes, particularly if the wastewaters contain a high fraction of normally non-biodegradable or slowly biodegradable materials. There is a synergistic relationship between the bacteria and carbon such that more organics become biodegradable in the presence of carbon. The PACT process removes over 96% of the BOD and over 80% of the DOC in Chambers Works wastewater.

2. A PACT plant is resistant to upsets, can tolerate shock loads of organic compounds, and is tolerant to rapid changes in waste composition.

3. The PACT process can treat highly colored wastes, including dye wastes. With Chambers Works wastewater, 66% of the color is removed.

4. A long sludge age (more than 15 days) and low carbon dose (80-120 mg/liter) mode of operation is an effective way to operate the Chambers Works PACT plant. There are significant savings in activated carbon cost and the amount of solids to be wasted is lower.

5. The addition of powdered carbon to biological sludge in the PACT process drastically increases the thickening ability of a clarifier. In the Chambers Works plant with aerator MLSS containing from 50 to 65% activated carbon, the clarifiers can deliver an underflow with approximately 7% solids concentration at a solids flux rate of 1,400 kg/day-m^2 (280 lb./day-ft^2).

6. The filtration rate of PACT sludge increases with increasing carbon content. In the Chambers Works system there was a sharp increase in filtration cycle time if the activated carbon content of the MLSS dropped below 50%.

7. Based on the Chambers Works experience, it should be relatively easy to start up a PACT process using normal wastewater. A synthetic, easily biodegradable feed is not needed, even with aerator temperatures in the 15°C range.

8. Powdered activated carbon can be regenerated from PACT sludge in a multiple hearth regeneration furnace. Carbon has been regenerated in the multiple hearth furnace at over 90% yield and over 70% recovery of virgin properties, although the full two year average has been 80% yield and 63% quality recovery. Thermal regeneration has been successful even with carbons that were partially chemically activated when manufactured. Better regeneration performance is anticipated with better control of furnace operating conditions. There has been no measurable, further loss of carbon activity on successive regenerations when the regenerated carbon was washed with acid to remove ash.

9. The Chambers Works WWTP sludge conveying system was underdesigned, in part because the wide variation in sludge rheological properties was not anticipated. Operation at lower carbon dose than anticipated has made the sludge difficult to handle, as it contains a higher fraction of slimy biological solids. Conveyor outages have significantly hurt furnace performance.

10. The erosive nature of powdered carbon must be considered in handling slurry at more than 3% concentration and fluid velocities over 2 m/sec. Similarly mechanical equipment to handle filter cakes of PACT sludge must be designed to withstand erosive wear.

11. The single PACT filter press for the Chambers Works wastewater treatment was not sufficient to handle the solids load. Cycle times were longer than anticipated and downtime was high.

12. The Chambers Works experience indicates that it is easier to pump a slurry of PACT solids than convey filter cake. A PACT filter should be located to minimize the distance cake has to be transported to the next processing step.

13. A 20 to 50% higher dose of carbon is needed for the same degree of treatment at 15°C as can be attained at 35°C. (Figure 12)

14. The most important measurements for control of the Chambers Works PACT process are DOC concentration in the feed and effluent, and the dissolved oxygen level in the aerators. The use of continuous, on line analyzers to measure these parameters is extremely valuable. Continuous pH control and monitoring of primary effluent is critical because the wastewater feed to the plant is strongly acidic.

15. Static mixers in the aerators give improved oxygen transfer over a no mixer system, but at a penalty in solids suspension.

16. In an attempt to minimize the chance of operator error, by automating the process as much as possible, an excessive number of interlocks were added to the instrumentation, particularly on the filter press and regeneration furnace. False readings due to instrument failures have been responsible for a significant (more than 10%) amount of the downtime suffered by this equipment.

17. Divers were successfully used to make on line repairs to the aerators; at a much lower cost than would have been incurred for a conventional repair which requires draining the aerator.

SECTION 3

RECOMMENDATIONS

Certain aspects of large scale PACT process operation which seem particularly worthy of further study are listed below. Most, if not all of these, will be investigated at the Chambers Works wastewater treatment plant in the next few years.

1. Study wet air oxidation (WAO) as an alternative to the multiple hearth furnace for carbon regeneration.

    Conceptually, a WAO unit can eliminate two major problem areas that exist with the current process, sludge filtration and filter cake conveying. WAO retains the important advantage of destroying the bio-solids, thereby eliminating disposal problems. The process is being successfully used on PACT sludge (Ref. 4). However the activated carbon used in that process is much lower in quality than that needed by the Chambers Works WWTP. Pilot tests are needed to demonstrate that high quality regenerated carbon can be made from Chambers Works PACT sludge by WAO.

2. Test a belt type filtration unit as an alternate to the existing high pressure filter press for PACT sludge.

    Using the feed slurry itself at a very high pressure to squeeze the filter cake may not be the optimum way to dewater PACT sludge. The mechanical squeezing action available with a belt filter would eliminate problems with holes in the filter cloths and might minimize cloth blinding. The maintenance problems with high pressure feed pumps would also be ended. Important questions which must be answered are whether the belt filter can deliver a high enough solids cake, and how well mechanical components would stand up to the erosive carbon. The amount and cost of conditioning agent(s) needed could significantly affect the economics of a belt filter.

3. Test PACT performance without the static mixers in the aerator.

   Data are needed to quantitatively compare gas/liquid mass transfer in a PACT aerator with and without static mixers. The choice for a given system may well depend on the BOD/DOC ratio, with mixers favored because of their better oxygen transfer when there is a high oxygen demand from the waste.

4. Improve utility of continuous DOC analyzers.

   Alternate sample feed systems need to be evaluated to find one which can better tolerate periodic slugs of high TSS. The current analyzers also require excessive instrument mechanic time.

5. Obtain better conveying equipment for PACT sludge filter cake.

   Neither a drag flite type conveyor, nor a screw, which kneads the cake into a gummy mass, seems suitable for the erosive carbon filter cake. Performance to date of the short weigh belt conveyors suggests that a belt is better suited for this service.

6. Finish plant test of dual liquid polymers to improve clarifier performance.

   The volume of wastewater treated at the Chambers Works is so large that use of even a few mg/liter of polymer costs over $100,000/year. Tests now in progress will determine if a dual, cationic-anionic polymer system is more cost effective than the original, single cationic polymer system.

7. Determine if direct addition of a polymer to the slurry feed to the PACT filter press will improve filtration.

   Facilities are needed to add polymer at the discharge of the high pressure filter feed pump(s). If polymer is added elsewhere, its effectiveness is destroyed by high shear in the pump.

8. Evaluate Electrolytic BOD (E-BOD) measurement of endogenous oxygen uptake as a monitor of bio-system health.

   E-BOD data show promise of being more sensitive than ATP analyses, and the test is easier to run.

SECTION 4

DESCRIPTION OF CHAMBERS WORKS WASTEWATER TREATMENT PLANT

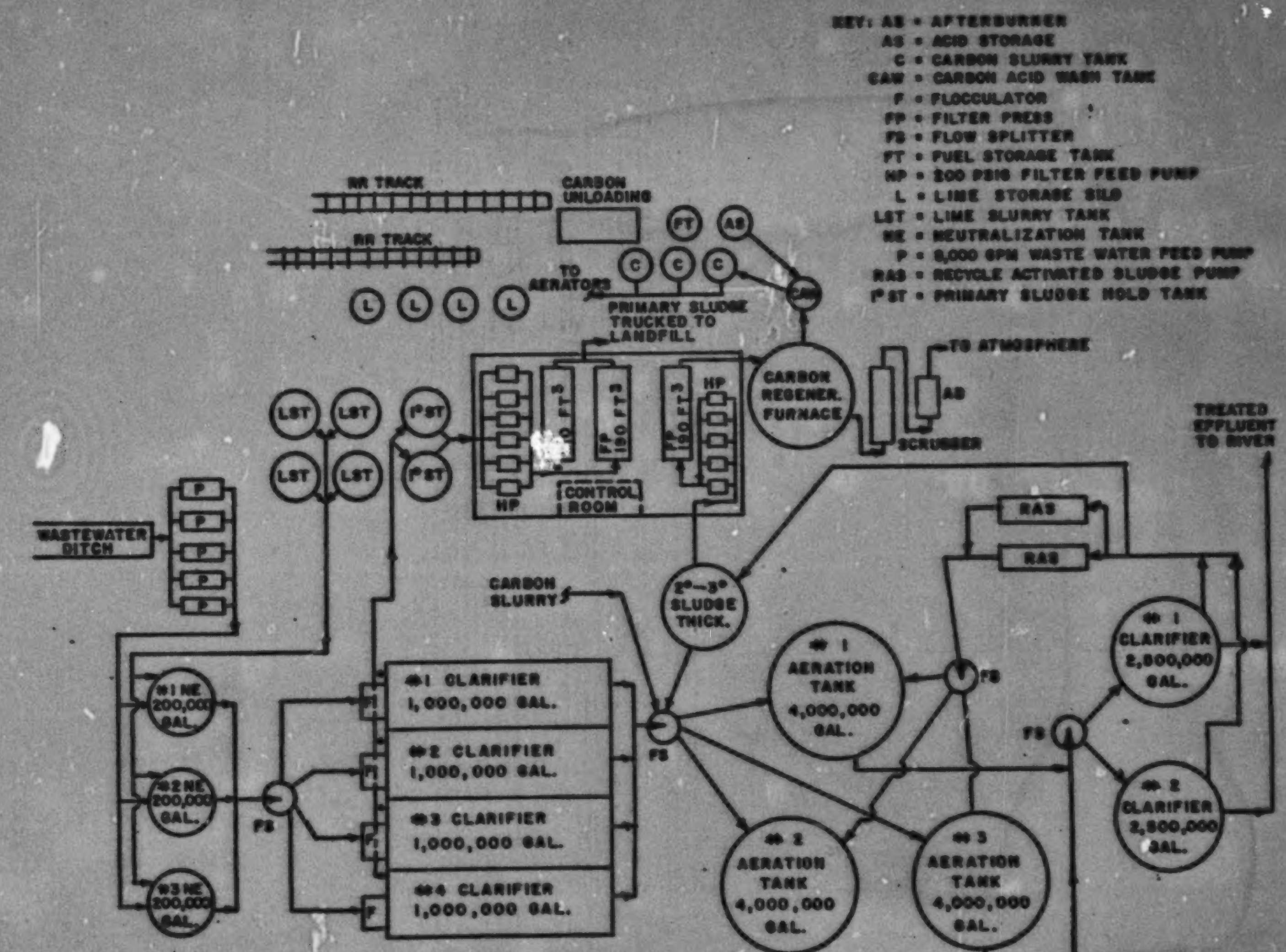
Figure 5 is a flow diagram of the plant showing equipment arrangement. Flow through the plant is by gravity starting with overflow from the neutralizers. Large centrifugal pumps raise the wastewater from a collection trench to the neutralizers.

PACT treatment starts at the flow splitter where neutralized primary effluent enters from the four primary clarifiers. A slurry of regenerated plus virgin make-up carbon is added to the wastewater here. Slurry flowrate is controlled to maintain the desired carbon dosage.

The wastewater is fed to three parallel aerators where it mixes with activated sludge and carbon recycled from the clarifiers. Each aerator has a volume of 15,100 m^3 (4,000,000 gallons) and provides about 7 hours hydraulic residence time. Static mixers in each aerator provide the mixing necessary to suspend the PACT sludge as well as providing oxygen transfer.

The aerators are tanks 56.3 m in diameter and 7.0 m in depth. Effluent from primary treatment and recycle activated sludge (RAS) flow from their respective flowsplitters and are combined in a common influent line which feeds the aerators. The feed line passes through the aerator wall, splits and distributes flow to six points in the aerator. Air is supplied through a tapered air header extending across the center of the tank along the floor. Forty-three air laterals 7.6 cm in diameter extend perpendicularly outward from this main header toward the tank walls. Air is supplied to 1172 reverse helix, static mixers via two downward pointed air holes 0.95 cm in diameter for each mixer. Water leaves the aerator via bottom take off lines from each aerator, which combine in a common 21.9 m diameter line which feeds the clarifier feed flowsplitter.

The two clarifiers are 9,460 m^3 (2,500,000 gal.) tanks which are 52.4 m in diameter and have a sidewall water depth of 4.6 m. The bottom slopes downward to about a 6.1 m water depth at the center. Feed enters a centerwell via an underground


KEY: AB = AFTERBURNER
AS = ACID STORAGE
C = CARBON SLURRY TANK
CAW = CARBON ACID WASH TANK
F = FLOCCULATOR
FP = FILTER PRESS
FS = FLOW SPLITTER
FT = FUEL STORAGE TANK
HP = 200 PSIG FILTER FEED PUMP
L = LIME STORAGE SILO
LST = LIME SLURRY TANK
NE = NEUTRALIZATION TANK
P = 8,000 GPM WASTE WATER FEED PUMP
RAS = RECYCLE ACTIVATED SLUDGE PUMP
1° ST = PRIMARY SLUDGE HOLD TANK
RR TRACK
RR TRACK
CARBON UNLOADING
FT
AB
C
C
C
CAW
TO AERATORS
L
L
L
L
PRIMARY SLUDGE TRUCKED TO LANDFILL
TO ATMOSPHERE
AB
SCRUBBER
CARBON REGENER. FURNACE
LST
LST
LST
LST
1° ST
1° ST
HP
FP 150 FT3
FP 150 FT3
FP 150 FT3
HP
CONTROL ROOM
TREATED EFFLUENT TO RIVER
WASTEWATER DITCH
P
P
P
P
P
RAS
RAS
CARBON SLURRY
2°–3° SLUDGE THICK.
#1 NE 200,000 GAL.
#2 NE 200,000 GAL.
#3 NE 200,000 GAL.
FS
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F
#1 CLARIFIER 1,000,000 GAL.
#2 CLARIFIER 1,000,000 GAL.
#3 CLARIFIER 1,000,000 GAL.
#4 CLARIFIER 1,000,000 GAL.
FS
#1 AERATION TANK 4,000,000 GAL.
#2 AERATION TANK 4,000,000 GAL.
#3 AERATION TANK 4,000,000 GAL.
FS
FS
#1 CLARIFIER 2,500,000 GAL.
#2 CLARIFIER 2,500,000 GAL.

Figure 5. Flow diagram of Chambers Works wastewater treatment plant.

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line. The mixed liquor overflows the center well to a flocculating zone created by a steel ring 20.7 m in diameter which is suspended from the clarifier bridge and protrudes down into the liquid. Within the flocculating zone are three mixers to gently mix the slurry and allow polymer, which was added at the flowsplitter, to act on the suspended solids.

Mixed liquor flows beneath the flocculator ring into an annular area bounded by the clarifier wall. Here solids settle to the bottom. Treated wastewater overflows into a circumferential trough, and then to the main effluent header. From there it drops to the effluent trench and the final settling basin prior to discharge to the Delaware River estuary.

Recycle activated sludge (RAS) or underflow from the clarifiers is pumped back to the second aerator flowsplitter by two screw pumps 0.2 m (78 inch) in diameter. The vertical lift is 5.4 m, and each pump has a rated capacity of 46.2 m^3/min. (12,200 gpm).

Pumps are provided to feed either aerator effluent or RAS to the carbon thickener. The thickener is a tank 18.3 m in diameter with a bottom sloped 12:1 to the center where liquid depth is approximately 5.2 m The thickener has a center drive rake mechanism which rakes solids on the bottom of the tank to the center discharge. Supernatant effluent overflows a peripheral weir and is returned to the aerators.

Approximately 10% slurry from the thickener is fed to a 40.1 m^3 filter feed tank. Originally five hydraulic activated, 0.32 m^3/min., piston pumps fed the PACT filter press (FP-277). Because of continual maintenance problems, one of these was removed so a single triplex, piston pump could be installed. The remaining four original pumps are used to feed PACT sludge to the swing press, FP-76, when it is in PACT service. Two large 9.5 m^3/min. precoat pumps and a precoat make-up tank are also provided.

The horizontal filter press is an automatic unit operating at 17.6 kg/cm^2 (250 psig). It has 112 recessed chambers which are 2.54 cm deep and 1.62 m in diameter. An 18.9 m^3 equalization tank rated at 22.1 kg/cm^2 (300 psig) is connected to the press. Its purpose is to simultaneously fill the press at the end opposite to the feed pump. This equalizes the feed flow as much as possible during the very rapid initial filling of the press.

Filter cake drops into a 9.9 m^3 (350 $ft.^3$) bunker (CY-281) with a variable speed, 14.3 m drag chain flite conveyor on the bottom. Conveyor speed varies from 0.15 to 1.2 m/min. CY-281 now discharges to a 24 m constant speed (4.6 m/min) drag chain flite conveyor (CY-282). This "L" shaped conveyor moves sludge to the top of the filter building roof. From there a short screw conveyor (CY-292) feeds a 24.4 m inclined screw conveyor (CY-293) which carries the sludge at an 8° incline to a platform on top of the regeneration furnace. CY-293 feeds a short reversing screw conveyor (CY-294) which feeds either of two 4.9 m, continuous, rubber, weigh belt conveyors (CY-302A & B). Each weigh belt drops cake into its own 0.30 m x 0.30 m air lock with double flapper valves. The air locks minimize air leakage into the furnace which operates at a slight vacuum.

The PACT sludge drops onto the center of the # 1 (top) hearth of the 7.85 m (26 ft.) diameter multiple hearth regeneration furnace. There are five hearths in the furnace. Hot gases from an external fuel oil fired burner are fed into the bottom (# 4 and # 5) hearths. The furnace has a rotating centershaft with two rabble arms on each hearth. Solids are raked to drop holes at the outer edges of hearths # 1 and # 3. On # 2 and # 4 they are moved to the center of the hearth, where there is an annular hole around the center shaft through which the solids drop. There are some unique features to the furnace, all of which are designed to reduce upward gas velocity and thereby minimize entrainment of carbon particles. Special hearth spacings are used and the drop holes have been modified to try and separate the rising hot gases from the dropping carbon. There are metal chutes on the rabble arms over the inner hole of hearths # 2 and # 4. These are supposed to collect the carbon and drop it to the hearth below.

The principal of operation is that water is evaporated from the sludge on hearths # 1 and # 2 at gas temperatures from 480° to 700°C. On hearth # 3 the biological solids and adsorbed organics are burned off by 750° to 870°C gas. On the bottom two hearths, at gas temperatures from 870° to 1020°C, the powdered carbon is reactivated in the presence of water vapor. Oxygen concentration should be low on these hearths to minimize carbon oxidation. About one-half of the heat input to the furnace is supplied by a 2,650,000 kg-cal/hr burner. It is fired with No. 2 fuel oil and uses 11.6 kg/cm^2 (150 psig) atomizing steam.

Combustion chamber temperature is controlled by adjusting air and feed to the burner. Scrubber off gas is recycled to the combustion chamber as a secondary means of cooling the combustion chamber as well as providing water for the regeneration reaction. Secondary air can also be fed to the combustion chamber to control oxygen concentration which should be in the range of 2% to 6%.

Incandescent powdered carbon is rabbled through a grate at the outer edge of the # 5 hearth into a 2.2 m^3 quench tank. Sufficient water is fed to the tank to give a 5% slurry concentration. The slurry is continuously withdrawn and fed to an acid wash tank.

Off gas from the # 1 hearth passes through a venturi scrubber 4.27 m in height and 0.71 m in diameter. Particulates removed in this water scrubber are separated from the gas in a separator 1.5 m in diameter and 1.8 m in height. The gases pass upward through a wet tray impingement scrubber. A portion of this gas stream becomes the recycle off gas to the combustion chamber. A separate recycle gas fan is used for this transfer. Venturi scrubber discharge water is recycled back to the venturi scrubber, after draw off of a purge stream to the product quench tank, and addition of make-up water. The main furnace induced draft fan collects most of the impingement scrubber off gas and discharges it into the afterburner. This oil fired burner heats the off gases to over 650°C for a 3 second residence time. Oxygen concentration at the base of the afterburner stack is 10% to 12%. Any organics in the gas are oxidized to carbon dioxide and water, and odor is destroyed.

The continuous, stirred, acid wash tank for the regenerated carbon slurry is an 0.89 m^3 plastic tank providing a nominal 2.5 minute hold up. Acidified slurry containing dissolved ash overflows into a water dilution jet. Diluted slurry at about 1% solids concentration feeds a carbon thickener tank 7.6 m in diameter. A 10 to 12 wt.% slurry discharges from the bottom of this tank to the carbon slurry tank from which the aerators are fed. Overflow from the thickener is returned to primary treatment where the dissolved ash is precipitated by lime neutralization.

Three 227m^3 (60,000 gal.) storage tanks are available to store slurries of regenerated and make-up virgin carbon. Virgin carbon is fed to the storage tanks from railroad cars by a vacuum blower, cyclone separator, rotary air lock, and screw conveyor system. As the aerators require some added phosphorus nutrient, a 22.7 m^3 (6,000 gal.) plastic storage tank suitable for 75% phosphoric acid is available. The plant tank farm also includes two 94.6 m^3 (25,000 gal.) plastic HCl tanks to store 12 to 35% acid for carbon washing. There is also a 75.7 m^3 (20,000 gal.) steel fuel oil tank and heated pumping system suitable for either No. 6 or No. 2 fuel oil.

SECTION 5

RESULTS AND DISCUSSION

LIQUID TRAIN

Performance

In the first 30 months of full scale operation, the PACT process has exceeded expectations in terms of BOD and color removal. Effluent DOC concentration has been lower than forecast, and the percent removal has almost equalled forecast. Average performance for 24 months (Jan., 1978 thru Dec., 1979) is summarized in Table 4 below. Detailed performance and operating data by month are shown in Table A-I. These data are plotted by day in Figures A-1 thru A-9.

TABLE 4. PACT SYSTEM PERFORMANCE, 1978 & 1979

Flowsheet	24 Month Avg.	Design
Flow	94.2 m^3/min (36 MGD)	100 m^3/min (38 MGD)
Inlet Soluble BOD_5, mg/l.	171	280
Effluent Soluble BOD_5, mg/l.	6.7	21
% Removal	96	93
Inlet DOC, mg/l.	170	205
Effluent DOC, mg/l.	31.2	35
% Removal	82	83
Inlet Color, APHA	1530	1000
Effluent Color, APHA	483	500
% Removal	66	50

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Even more important, in terms of meeting NPDES permit limits at the ultimate Chambers Works river outfall, performance has been very consistent. Figures 6 thru 11 graphically show the narrow distribution of effluent concentration in terms of critical waste parameters vs. wide variations in feed concentrations. This performance has been achieved even though the wastewater is more highly colored and contains a higher ratio of non-biodegradable organics than expected. During the design period the ratio of BOD to DOC in Chambers Works wastewater ranged from 1.3 to 1.5. Since start-up of the plant it has been approximately 1.0, indicating a less biodegradable waste. Apparently major source treatment efforts in the production areas, just prior to start-up of the WWTP, removed a preponderance of the more easily treated organics from area waste streams.

Normally non-biodegradable or very slowly degradable materials are being removed in the presence of the activated carbon. Laboratory studies (Ref. 2) show better DOC removals with a PACT system than from separate, successive treatment by activated sludge and powdered carbon. Recent respirometry work shows higher endogenous O_2 uptake from equal amounts of PACT MLSS vs. straight activated sludge MLSS. The better the quality of the carbon in the MLSS, the higher the O_2 uptake.

The PACT system has been very effective in removing EPA designated, organic, priority pollutants (Ref. 5). Table 4, taken from Reference 5, shows GC/MS data for feed and effluent to the Chambers Works PACT process. Both volatile organics and acid entractable compounds are removed well; base-neutral compounds are not as well removed. Some removal of metals occurs across PACT, but the process is not designed for metals treatment.

A major reason for selection of the PACT process was the protection that powdered carbon afforded the bio-system from toxic upsets caused by shock loads of specific organic compounds. Because of the variety and large number of batch production operations at Chambers Works, it is not uncommon for the WWTP to receive 10,000 kg. slugs of various organics over a 1 to 4 hour period. The bio-system has handled, with no ill effects, known spills of 23,000 kg. of an aromatic diamine and 14,000 kg. of a toluidine.

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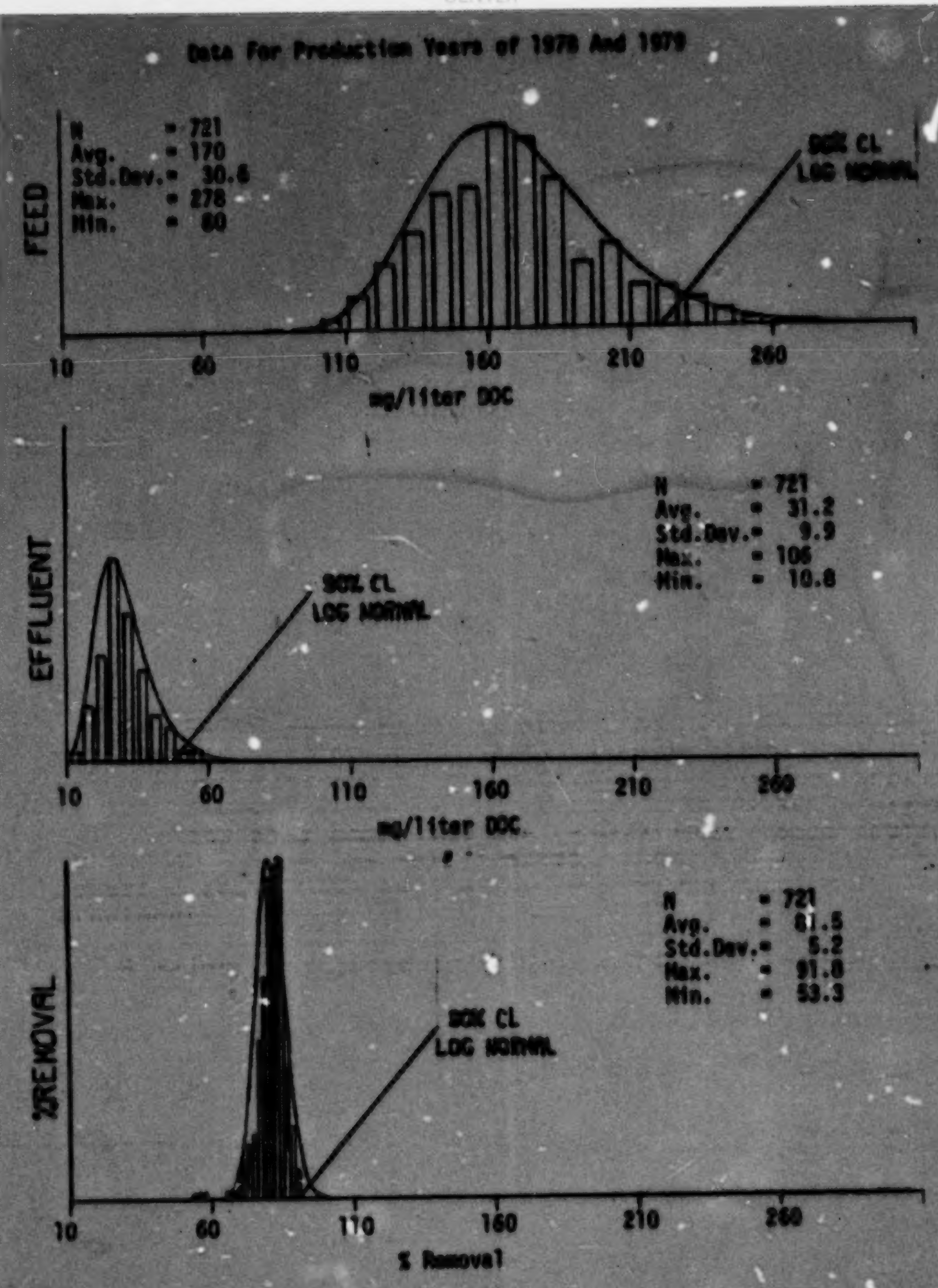

Figure 6. Histogram of DOC concentration in PACT feed and effluent, and % removal.

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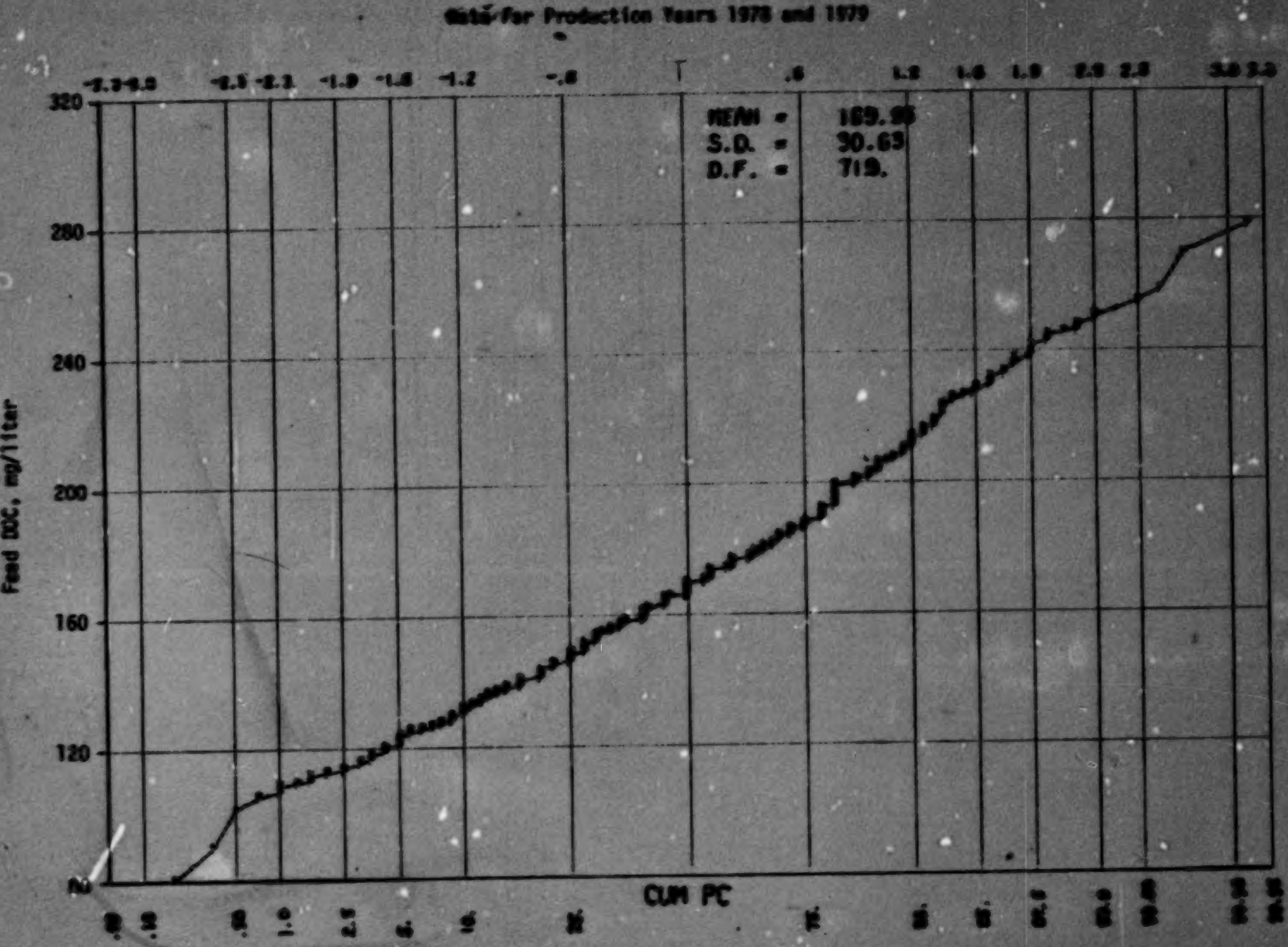

Figure 7A. Cumulative distribution of DOC in PACT feed.

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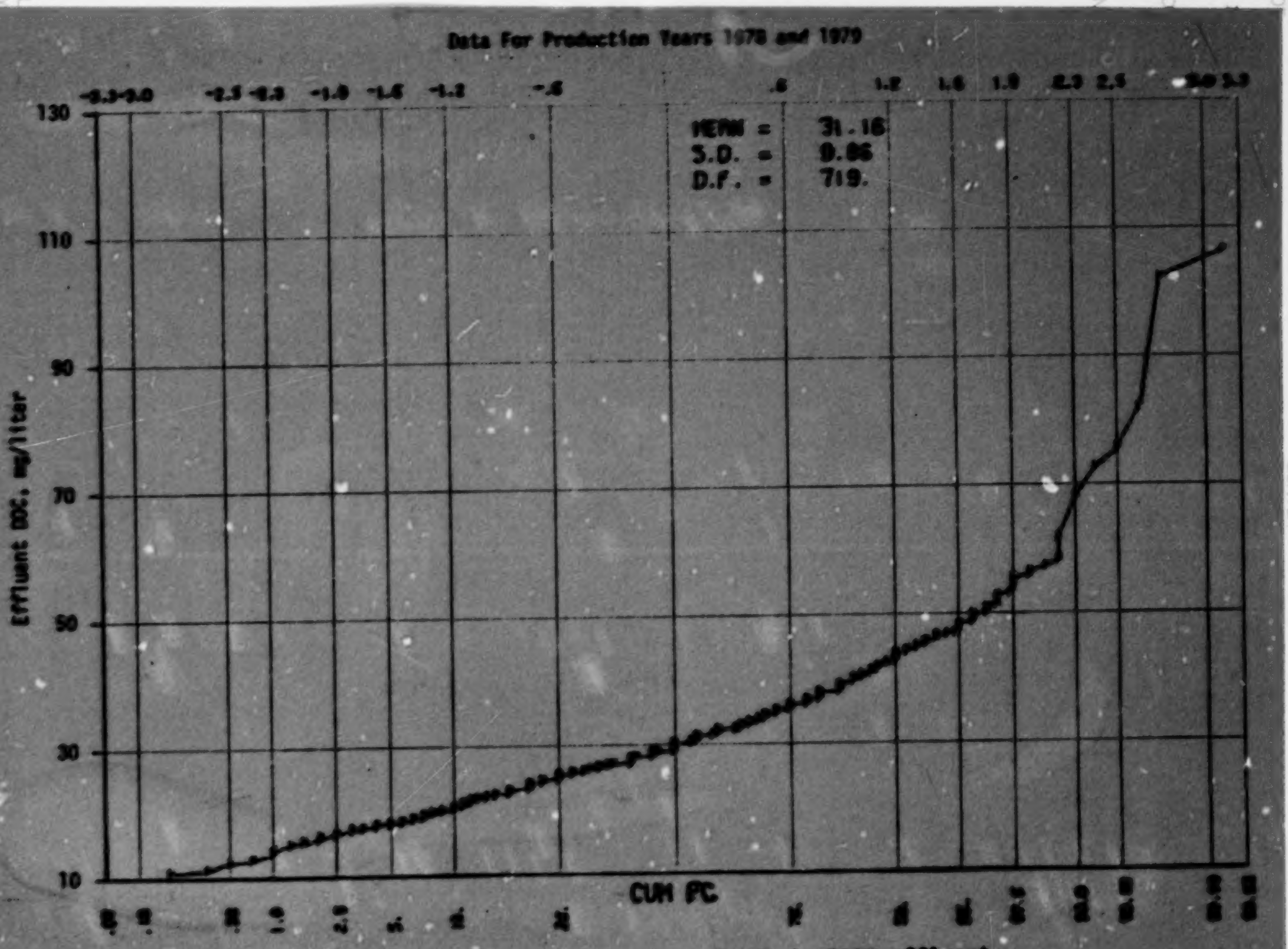

Figure 7B. Cumulative distribution of DOC in PACT effluent.

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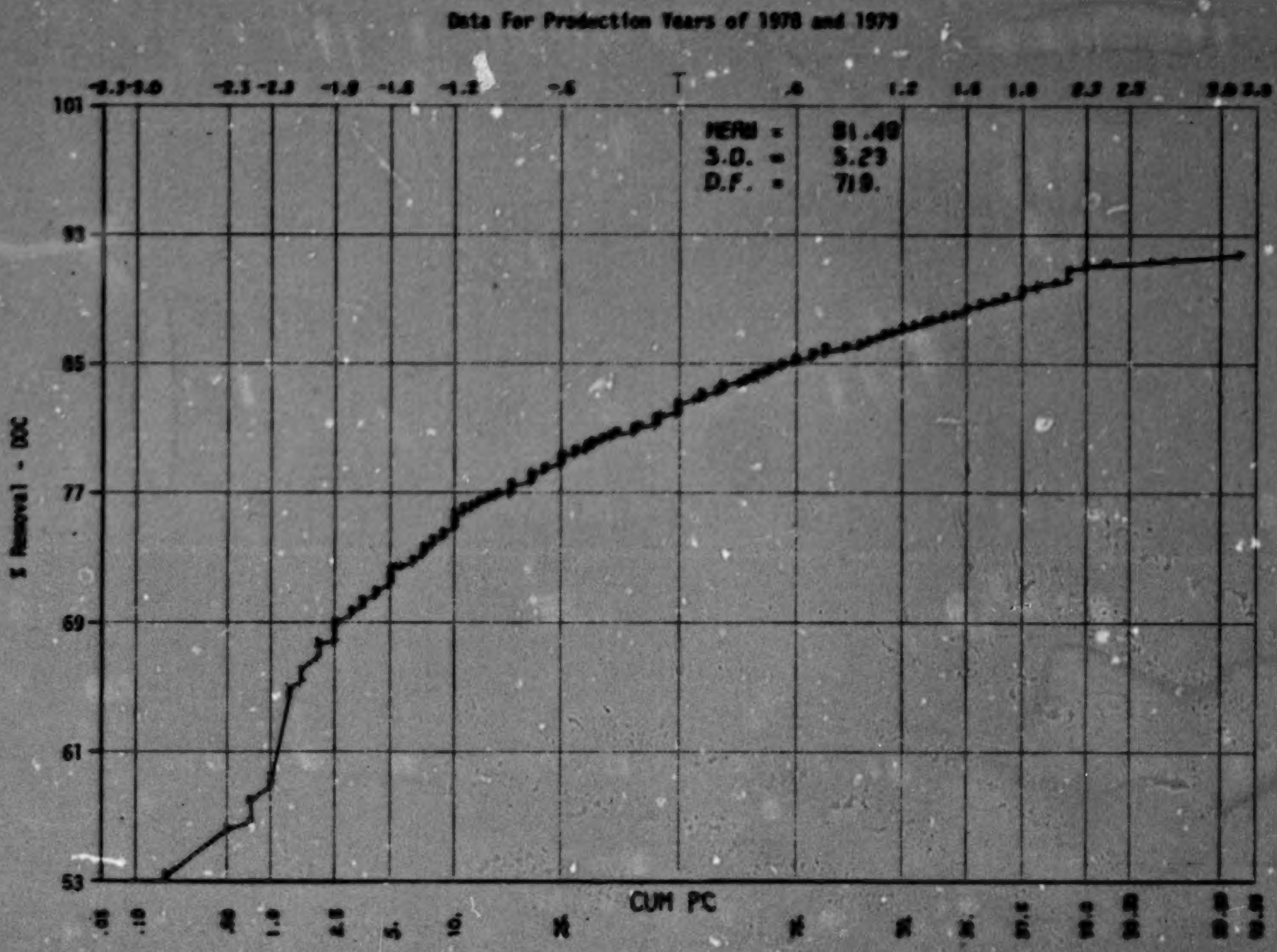

Figure 7C. Cumulative distribution of % DOC removal.

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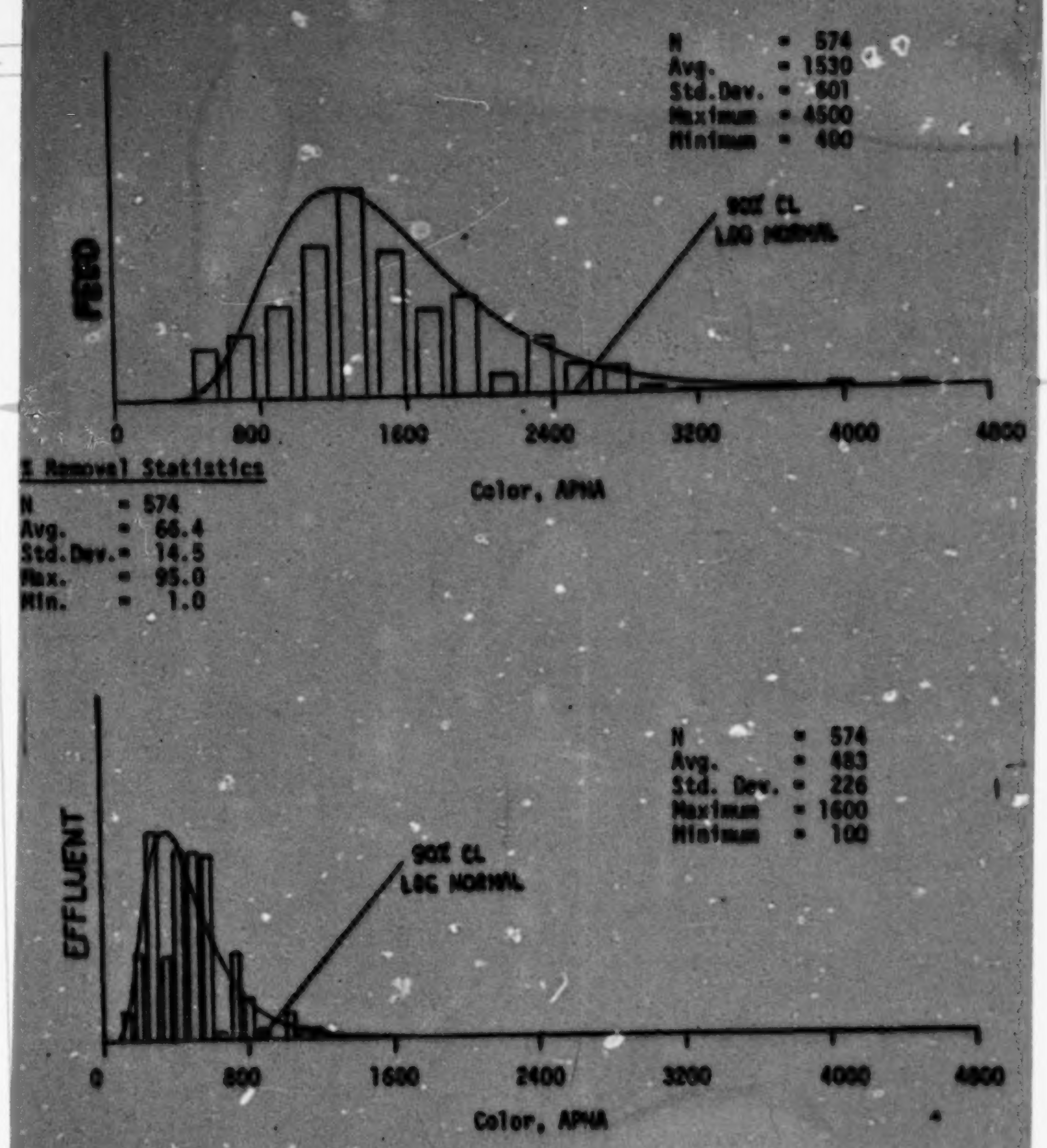
Data For Production Years of 1978 and 1979



N = 574
Avg. = 1530
Std.Dev. = 601
Maximum = 4500
Minimum = 400

% Removal Statistics

N = 574
Avg. = 66.4
Std.Dev. = 14.5
Max. = 95.0
Min. = 1.0

N = 574
Avg. = 483
Std. Dev. = 226
Maximum = 1600
Minimum = 100

Figure 8. Histogram of color in PACT feed and effluent.

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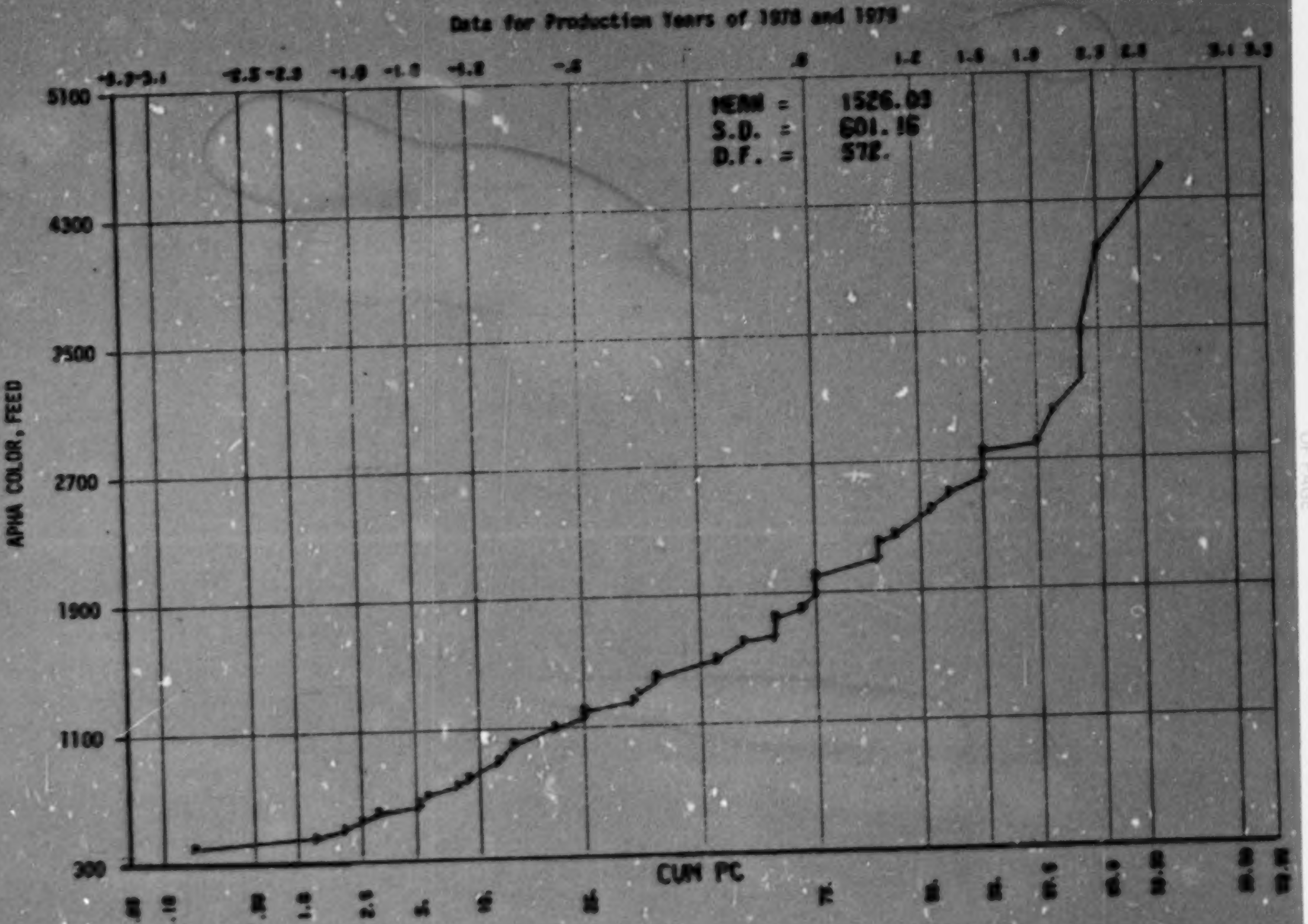

Figure 9A. Cumulative distribution of color in PACT feed.

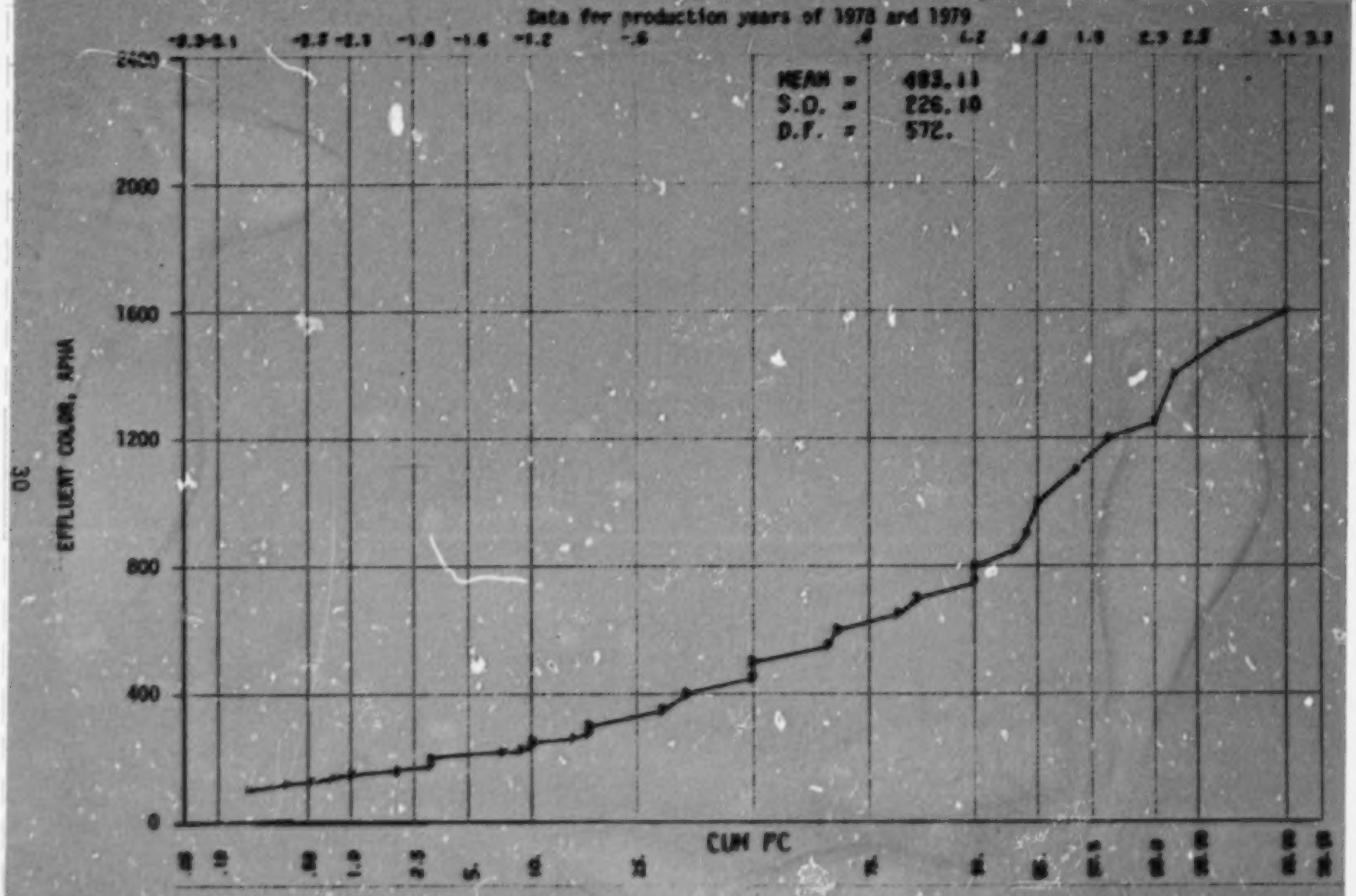

Figure 9B. Cumulative distribution of color in PACT effluent.

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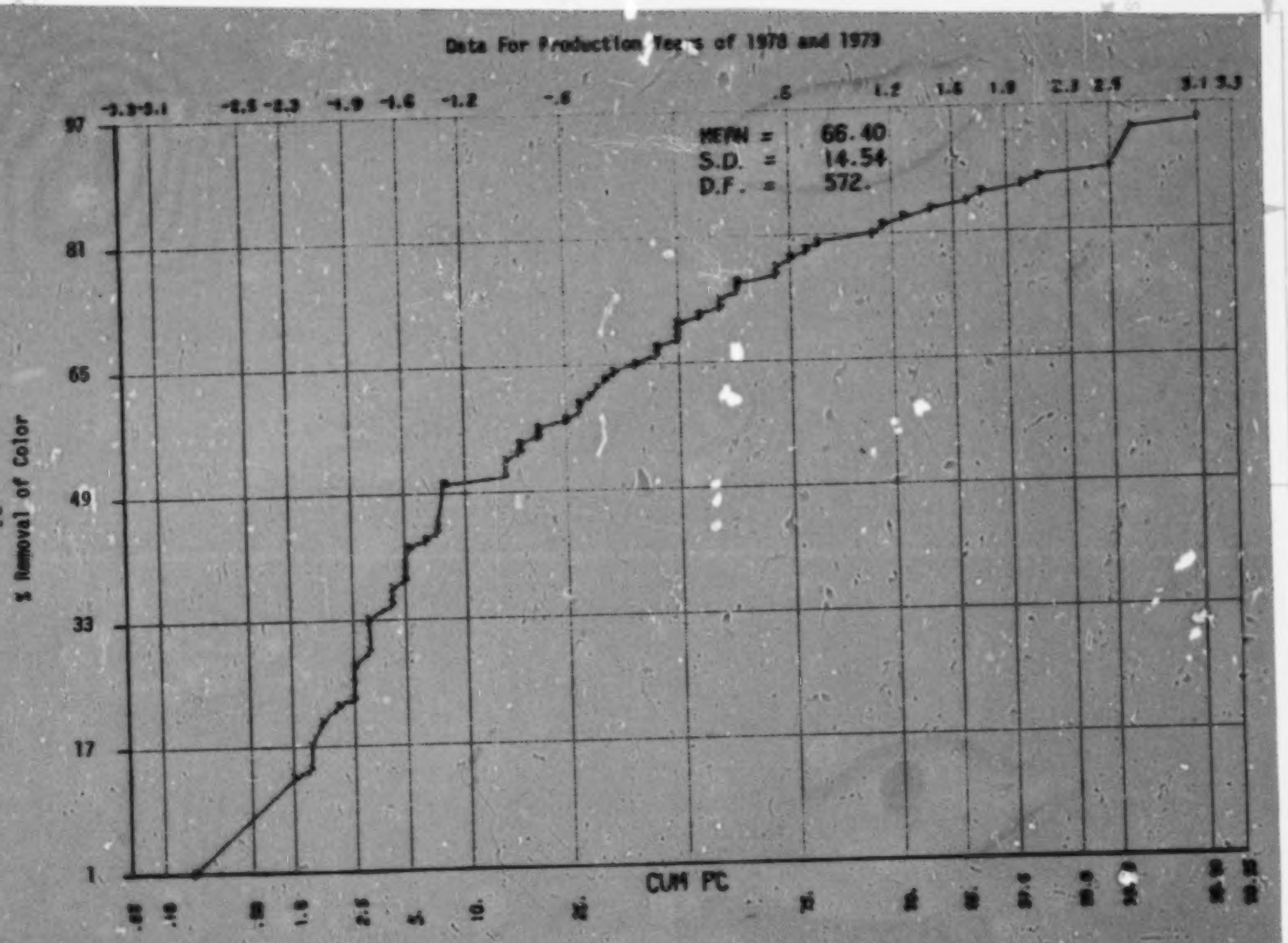

Figure 9C. Cumulative distribution of % color removal.

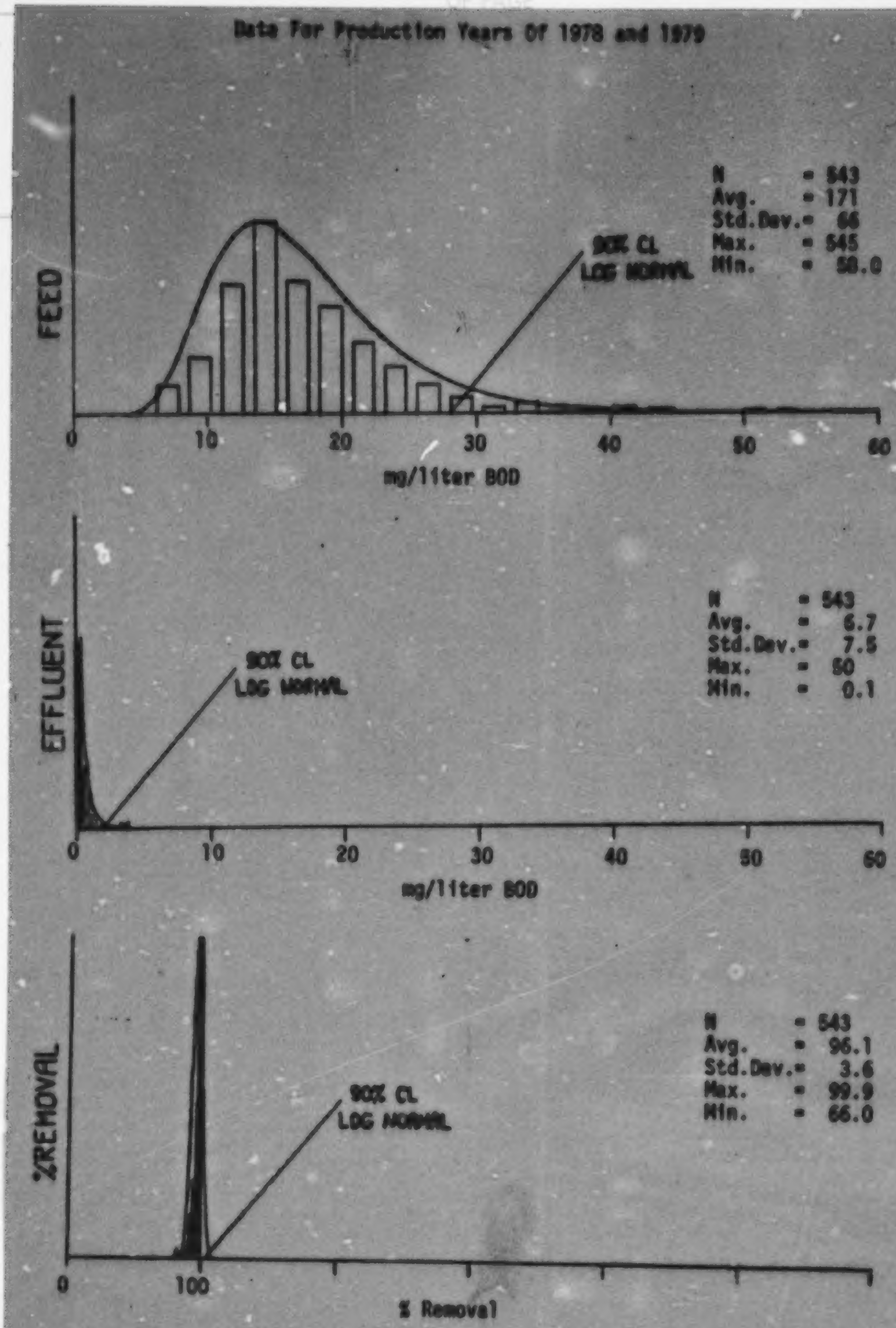

Figure 10. Histogram of soluble BOD_5 concentration in PACT feed and effluent, and % removal.

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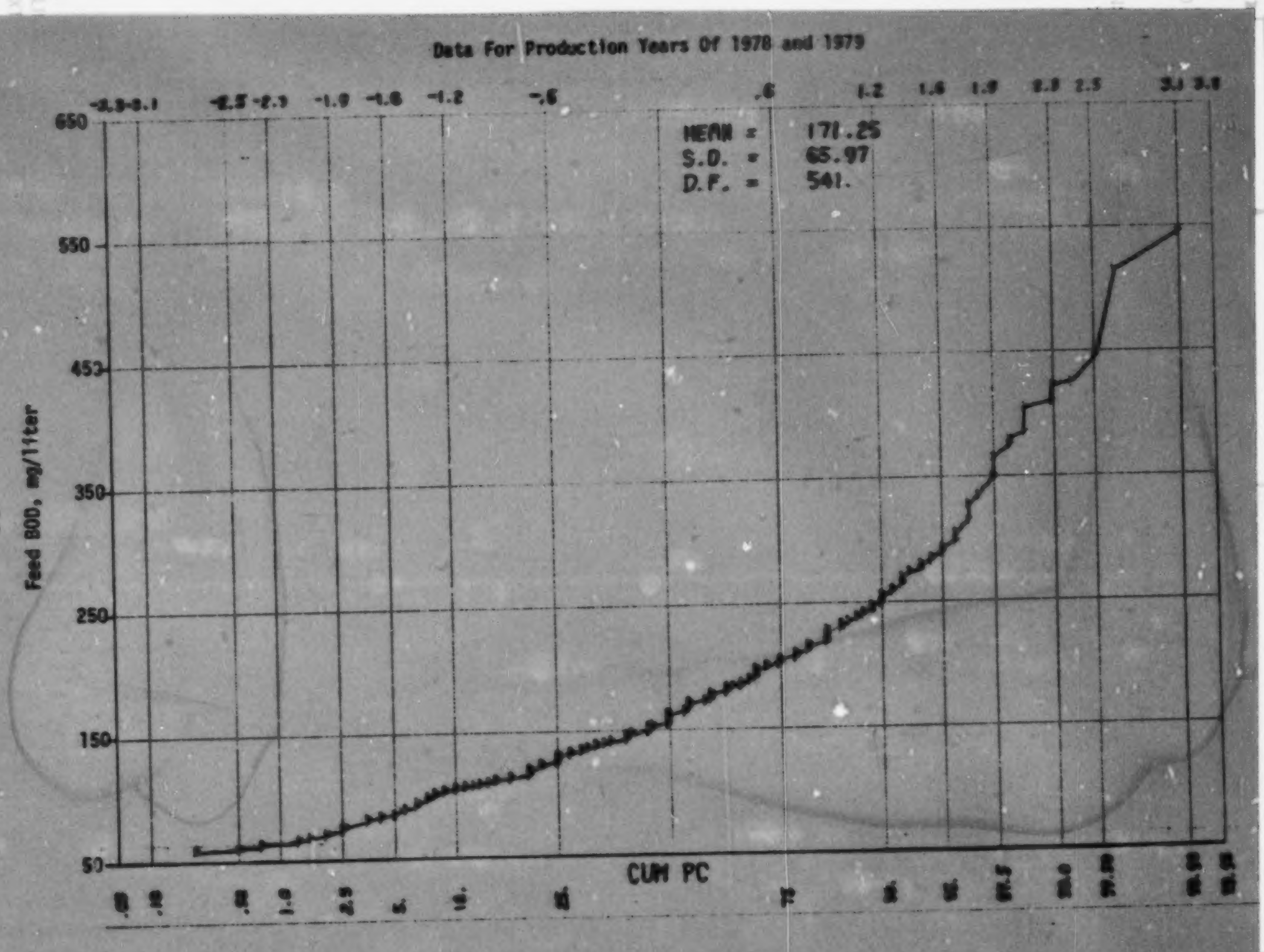

Figure 11A. Cumulative distribution of soluble BOD5 in PACT feed.

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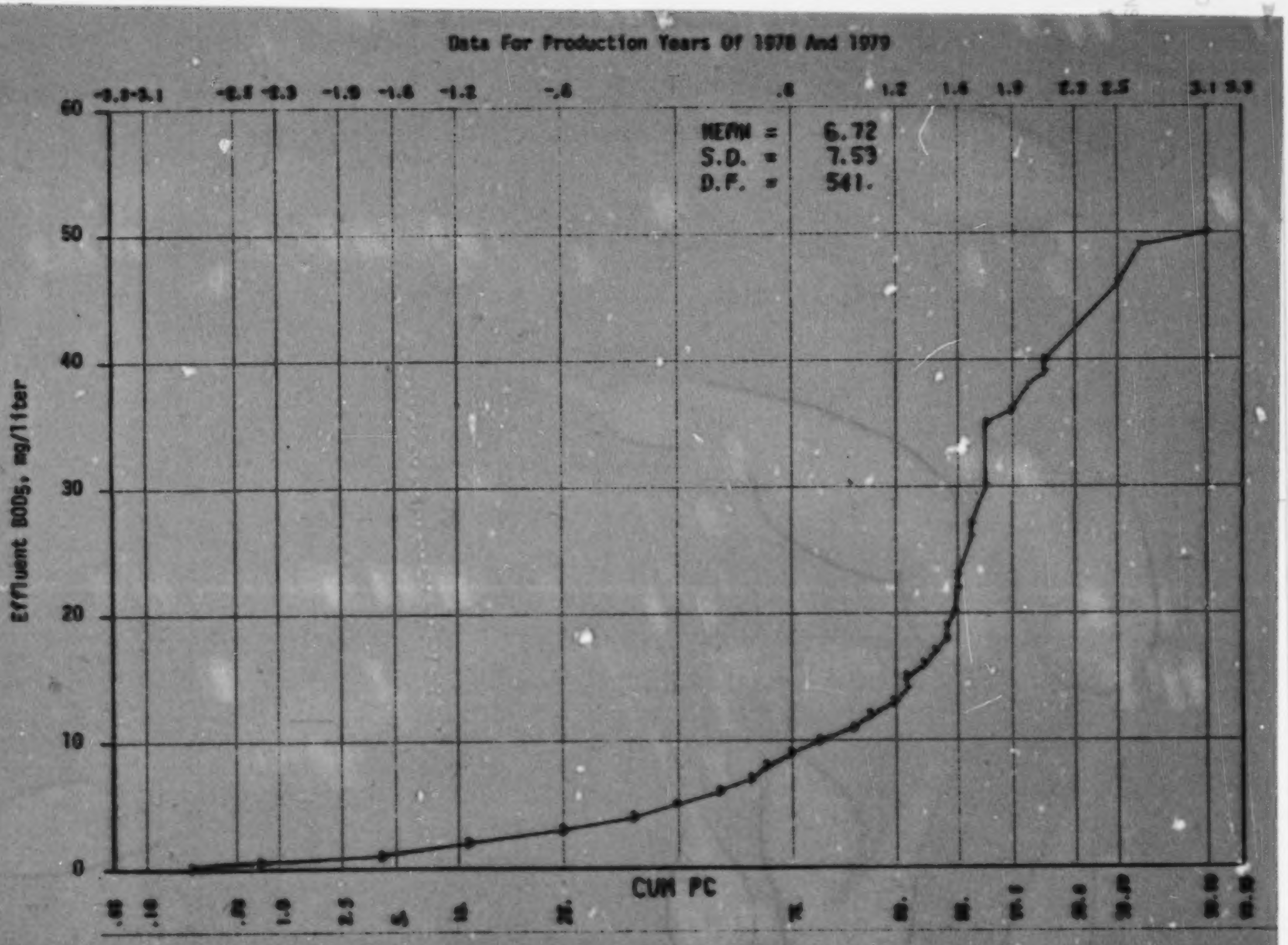

Figure 11B. Cumulative distribution of soluble BOD_5 in PACT effluent.

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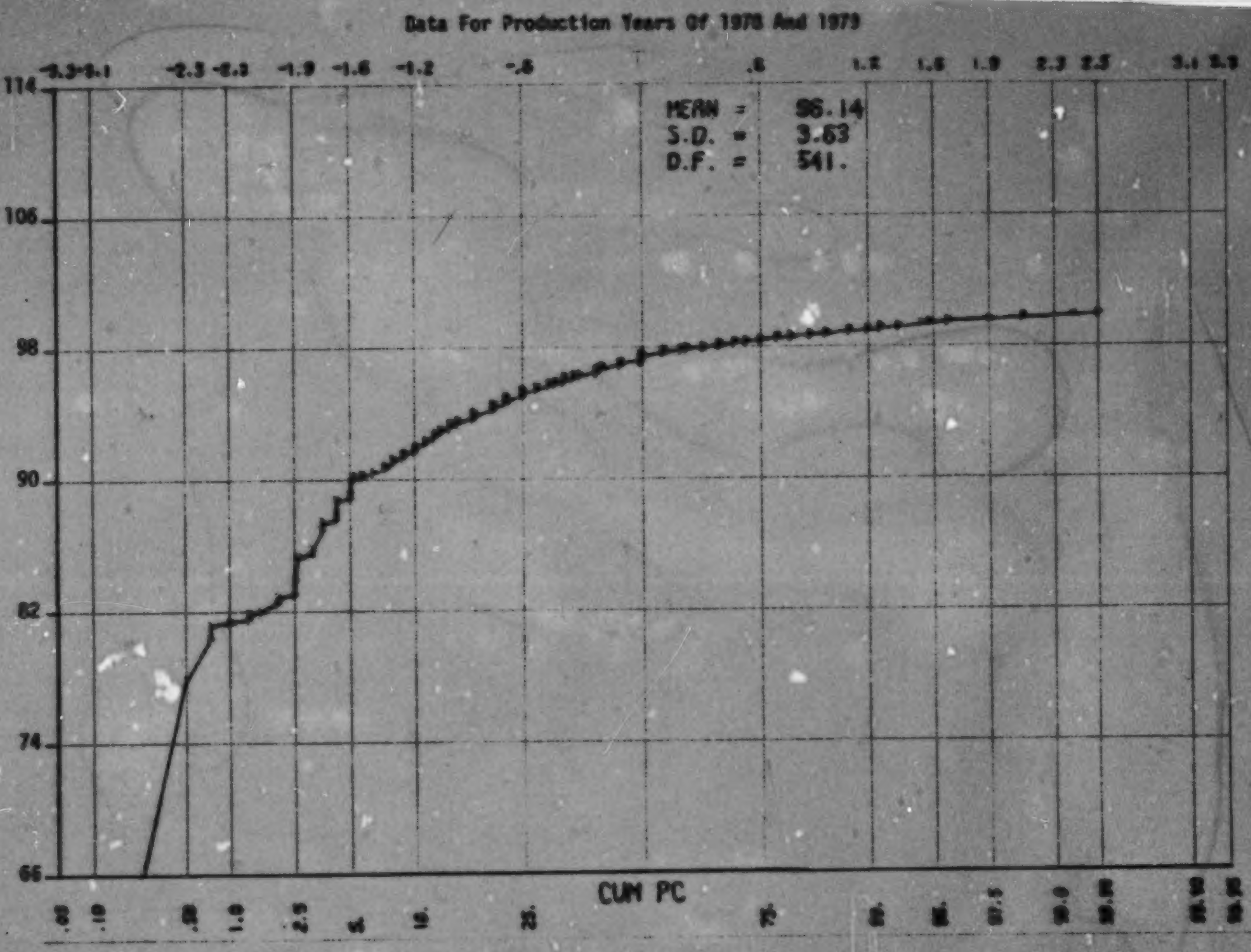

Figure 11C. Cumulative distribution of % soluble BOD_5 removal.

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TABLE 5. PRIORITY POLLUTANT REMOVALS* ACROSS PACT SYSTEM

Compound	Concentration in ug/liter (ppb) Feed	PACT Effluent	% Removal
Volatile Organics			
Benzene	105	0.9	98
Carbon Tetrachloride	94	1.4	95
Chlorobenzene	1720	30	98
Chloroethane	280	12	94
Chloroform	201	21	81
Ethylbenzene	41	1.7	94
Methyl Chloride	1770	Nil	99
Tetrachloroethylene	24	1.7	93
Toluene	519	1.7	99
1,1,1-Trichloroethane	13	0.6	89
Trichloroethylene	41	1.9	94
Trichlorofluoromethane	155	3.0	95
Base-Neutral Extractables			
1,2-Dichlorobenzene	259	120	44
2,4-Dinitrotoluene	1900	243	65
2,6-Dinitrotoluene	1640	575	64
Nitrobenzene	454	2	99
1,2,4-Trichlorobenzene	523	169	66
Acid Extractables			
2-Chlorophenol	11	1.6	95
2,4-Dinitrophenol	161	5.0	98
4-Nitrophenol	1020	10	97
Phenol	489	38	94
Metals			
Antimony	24	24	42
Arsenic	19	21	Nil
Beryllium	1.4	1.0	29
Cadmium	5.6	5.4	4
Chromium	26	15	42
Copper	72	75	Nil
Lead	112	54	52
Mercury	.02	.01	50
Nickel	77	59	23
Selenium	29	23	21
Zinc	602	360	40

*The above values are averages of data which show significant day-to-day variations in removals. Results were obtained by GC/MS analyses of plant samples and are subject to analytical error. The above represents our current best estimates of average percent removals for these materials.

There is no equalization provided prior to treatment. After pilot plant studies demonstrated the shock resistance of the PACT process, it was decided to eliminate this portion of investment from the WWTP. During a single day the inlet DOC concentration will normally vary by a factor of two, although on very rare occasions it has varied by as much as a factor of five. The daily average DOC load is usually within 30% of the load of the previous day.

In 30 months of full scale operation there have been only three instances when an upset has seriously diminished PACT system performance. In these cases, DOC removal dropped to the 50-60% range for up to 3 days and was below normal for up to 20 days. BOD and color removals dropped correspondingly. However, in no case has there been anything even close to a complete kill of the bacteria.

The first upset occurred in July, 1977 and was partially attributed to a weakening of the bio-system at high temperature, 38.4°C daily average. Since this was shortly after start-up, evasive measures which are now taken routinely at the first sign of upset were not implemented. This probably increased the severity of the upset. The second and third upsets occurred in October, 1978 and January, 1979. In the former case, identified abnormal conditions were: high carryover (180 mg/liter average) of solids from primary treatment for four days, the solids possibly containing heavy metals; lower quality activated carbon in the aerators; and rapid, seasonal temperature change in the aerators. The third upset coincided with a high level of cyanide from an undetermined source in the aerator. Unfortunately, the exact cyanide level in the MLSS could not be determined. Subsequent laboratory studies have shown that cyanide ion at concentrations above 0.1% in the MLSS can cause severe inhibition of even the PACT system. The general conclusion from these upsets is that an unknown compound or compounds, which would normally cause no more than a mild inhibition, did cause an upset in these cases because the bio-system was at less than full activity from other causes.

Since startup the WWTP has operated at higher sludge age and lower carbon dose than that for which it was designed. It had been postulated from laboratory work that this mode of operation might be desirable and plant tests were planned. However, from start-up, the plant was forced into this operating mode by capacity problems in the solids train. These have limited the wastage rate of MLSS from the aerators. As a result the aerators have operated at monthly average MLSS levels from 18,000 to 30,000 mg/liter and average sludge age has ranged from 20 to 60 days. Solids which are not wasted via the solids train must leave the system as TSS in secondary clarifier overflow (WWTP treated effluent). This has resulted in an average effluent TSS level of 103 mg/liter vs. a design value of 30 mg/liter.

Because of the high solids load throughout the system, the secondary clarifiers have been badly overloaded since start-up. Several process and mechanical modifications, which are discussed later, have not solved the basic problem; the solids have to go somewhere. The expected excellent solids settling rate has been seen in the clarifiers with PACT MLSS. The clarifiers were designed for solids flux rate of 308 kg/day/m^2 at an underflow concentration of 3.6%. They have operated at monthly average flux rates of from 1000 to 1700 kg/day/m^2. Monthly average solids concentration in the clarifier underflow has ranged from 4.1% to 7.5%. Since February, 1978, and based on average monthly flowrates, weir loadings have varied from 0.38 to 0.47 m^3/day/m.

WWTP effluent mixes with uncontaminated cooling water in a settling basin before discharging to the river. Overflowed PACT solids settle here. They are ultimately dredged back into the wastewater which is fed to primary treatment, and removed with the primary solids. This results in higher than forecast carbon losses, as this carbon is unavailable for regeneration. However because of much better aerator performance at high sludge age, the plant has been able to operate at an average carbon dose of 120 mg/liter, and still meet all the required effluent quality standards. As the design carbon dose was 180 mg/liter, the net carbon costs have been no higher than design projection. Two types of virgin carbon are used, Hydrodarco C (HD-C) and Nuchar SA (SA). Although other carbons have been tested, these are the only two of satisfactory quality which are available in sufficient quantity for our use. In the 24 months, January, 1978 to December, 1979, activated carbon feed has been 48% SA, 14% HD-C, 3% test carbons, and 35% regenerated carbon. Nuchar SA has been the most effective in treating Chambers Works waste, but it is also the most expensive.

As expected, biological activity has been a function of aerator temperature. As is shown in Figure 12, the carbon dose is increased in the winter to compensate for lower biological activity at low temperature. Despite the July, 1977 upset at 38.4°C, the plant operated well at daily average aerator temperatures up to 38.8°C in subsequent summers. Up to these temperatures bio-system performance appears to steadily improve. However, there are enough other factors affecting WWTP operation that only a general trend in the relationship among temperature, activity, and carbon dose has been determined.

Laboratory studies had shown a slight decline in PACT performance with decreasing hydraulic residence time in an aerator. Normal hydraulic residence time in the WWTP aerators is from 7 to 10 hours. In November, 1978 it was necessary to shut down one of the three aerators to repair breaks in the air laterals. The WWTP was designed to operate with only two aerators and did so successfully at residence aerator hydraulic times of 5 to 7 hours. The third aerator was placed back on line in January, 1979, in the hope that added residence time might hasten recovery from the January, 1979 upset. In retrospect it appears that the addition or removal of the third aerator had no effect on the course of the upset. When operating with two aerators the hydraulic capacity of the plant was reduced from 125 m^3/min. to 98 m^3/min. This was at maximum RAS flowrate, 45 m^3/min., which at that time was believed necessary to minimize solids carryover from the secondary clarifiers. At lower RAS rates a higher hydraulic capacity is available.

As expected, the 15,100 m^3 aerators have a significant buffering capacity. Primary effluent has been outside the 6.0-8.0 pH control range for up to 1.5 hours without driving the aerators outside their allowable pH range of 6.0-8.0. In one instance it was necessary to divert primary effluent back to the overflow basin for an hour when its pH had been over 10 for 1.75 hours. Aerator pH had risen to 7.9 before the diversion.

Operating Strategy

The most important repetitive decision is setting carbon dose. In effect this means that the virgin carbon dose, as regenerated carbon, must be recycled back into the system almost as fast as it is produced. The budgeted carbon dose for 1980 is 114 mg/liter of which 50% is to be regenerated carbon. At that rate the 227 m^3 (60,000 gal.) carbon slurry storage tank holds a maximum of only 4 days supply at an 86 m^3/min. wastewater feed rate.

Carbon dose must be sufficient to raise the level of biological treatment to meet a specified effluent quality. Operating limits on effluent quality are set to assure that, after WWTP effluent is mixed with 1.5 times its volume of non-contact cooling water in the settling basin, the combined effluent from Chambers Works main outfall meets NPDES permit

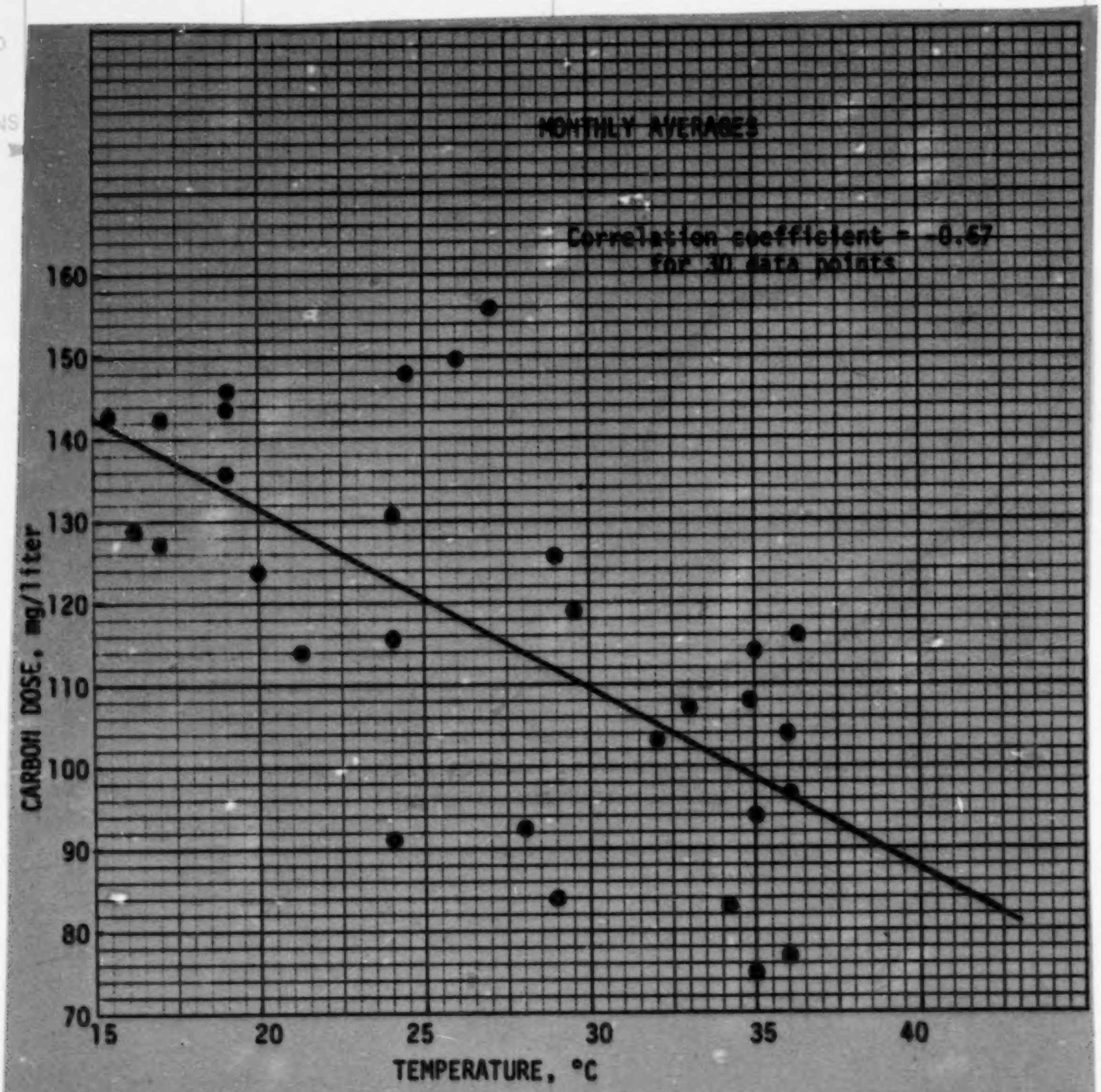

Figure 12. Carbon dose vs. aerator temperature.

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limits. In practice, this means that the carbon dose is adjusted based on the level of DOC and color in the plant effluent. When limits for these more refractory parameters are met, the BOD concentration is always well below the allowed limit.

At any specific time either color or DOC will be the controlling factor in setting carbon dose. Historically one has been as important as the other. In theory, carbon dose should be adjusted proportionally to the inlet concentrations of these parameters. However, as the composition of Chambers Works waste varies from day to day, so does the ease or difficulty of treatment. At the same inlet concentrations there can be drastic differences in the percent removals achieved at a given carbon dose. Further, 30 months of operating experience has shown that percent removals of DOC and color correlate better with the quality and amount of activated carbon inventory in the aerators rather than with the daily carbon dose. Since the plant has operated at sludge ages, or solids retention times, of over 20 days, it is impossible to drastically change the activated carbon content of the MLSS in a few days. Thus, despite a short term drop in inlet DOC or color, carbon dose still must be kept high enough to maintain an adequate concentration in the MLSS. The WWTP has generally been operated to maintain the percent removal of DOC above 80% on a several day average, which has assured compliance with NPDES permit limits.

There are two other constraints on carbon dose that are controlling at times. Laboratory studies have consistently shown that the higher the product of carbon dose and quality, the more resistant a PACT plant is to upsets. In effect, a high activated carbon level in the aerators is insurance against an upset of unpredictable magnitude which might occur at any time. It should be noted that the Chambers Works has successfully implemented a strong waste management program. Any major, abnormal discharge to the wastewater ditch must have prior WWTP approval, and any accidental spill is immediately reported.

A second, unexpected constraint on carbon dose has been PACT sludge filterability. Carbon in the sludge drastically increases filterability (Ref. 2), and advantage was taken of this in the design of the WWTP. The filtration capacity installed was less than would have been required for a similar capacity activated sludge plant. However the carbon dosages assumed during design were in the range of 130 to 180 mg/liter. By taking advantage of operation at long sludge age the WWTP has operated successfully at carbon doses as low as 50 mg/liter, particularly at warmer water temperatures and lower

DOC loads. Sustained operation at less than 100 mg/liter carbon dose lowers the activated carbon content of the MLSS below 50%. At this point filterability of the PACT sludge drops drastically. Particularly in the summers of 1978 and 1979, carbon dose often had to be held above that strictly necessary for DOC or color removal in order to sustain a minimum acceptable filtration rate in the PACT filter press.

Under the above conditions the cost effectiveness of different activated carbons changes. Cheaper carbons, lower in iodine number, become a viable option. With this in mind, some alternative carbons were tested in the WWTP; however, none were outstanding in cost effectiveness. There was also a reluctance to load the aerators with solids, in the form of less effective carbons, when there were severe limitations on the wasting rate for solids. In case of a surge of difficult to remove DOC or color, the aerator MLSS might not have had the reserve capacity to cope with it.

The best measure of the health of the bio-system has been percent DOC removal. However this is affected by inlet waste composition and concentration. In an effort to more directly measure the live bio-mass in the system, ATP analyses were tried. There was a general correlation, particularly during the initial seeding of the aerators (Ref. 6) and at the trough of upsets. However average aerator ATP values in the winter were twice summer levels. Measured ATP would also show equally large changes when there was no apparent reason for a change in the bio-mass and no indication from performance that there had been one. During the last 24 months of operation, ATP concentration has varied from 250 to 2200 parts per billion while the system has been operating satisfactorily. The ATP analysis is expensive and requires careful laboratory technique. The plant has recently abandoned ATP analyses. An electrolytic BOD (E-BOD) apparatus is now used to measure the endogenous oxygen uptake of aerator MLSS as a measure of bio-system viability. It is too early to tell how successful this will be as a control method.

The plant has evolved procedures for evasive actions in case an imminent upset is suspected. In order of priority, the procedures are to reduce wastewater flow, to increase air flow to the aerators, and to raise carbon dose by 100 mg/liter.

While the WWTP has no equalization basin, there is an excess flow basin with normal storage capacity of 40,000 m^3. The basin was provided to store excess rainfall, and in extreme cases, the basin has been filled in less than 8 hours even with the WWTP accepting its maximum flow of 125 m^3/min. Weather situation allowing, procedures now call for an automatic decrease in flow to 56 m^3/min. if inlet DOC concentration doubles within one or two hours. On-line analyzers give the operator continuous measurements of feed and effluent DOC concentrations. While such slugs of organics cause no problem over 99% of the time, automatic flow reduction provides a factor of safety and relieves the shift operator from having to make sophisticated judgements based on DO responses in the aerators. Flow is held down until DOC concentration drops or the plant supervisor decides it is advisable to increase it.

Each of the three aerators is equipped with two dissolved oxygen (DO) probes whose output is continuously displayed in the control room. It was initially planned that air flow to the aerators would be controlled at the higher of: 1) the flow needed to maintain an oxygen concentration over 2 mg/liter in the mixed liquor; or 2) the flow that provided a sufficient air velocity through the mixers to keep the MLSS well suspended. This latter velocity was expected to be between 0.28 m^3/min. and 0.14 m^3/min.

It was felt that most of the time the oxygen concentration in the aerator would be the factor controlling air flow. However, at the high MLSS levels at which the WWTP has operated, higher air flows than would be necessary to merely maintain oxygen concentration are needed for good solids suspension and higher levels of treatment.

A common response of the aerators to a shock load of an inhibitory compound is an initial decrease in oxygen concentration because of more organic oxidation. This is followed by a rise in oxygen concentration as bacterial activity slows and less oxygen is consumed. Bio-mass activity diminishes as the concentration of inhibitor builds up. At times this caused the operator to reduce air flow to save power costs since oxygen concentration would be well above guidelines. This is the wrong action to take in case of an incipient upset. Current procedures specify a normal air flow of 0.36 m^3/min. per mixer (1280 m^3/min. total to the three aerators) and a further increase in air flows if a shock load of inhibitory material is apparent.

The third evasive action now taken routinely is an automatic 100 ppm increase in carbon dose if effluent DOC rises above 50 mg/liter. An advantage of the PACT process is the ability to take some positive action to strengthen treatment when faced with a difficult to treat waste. It is impossible to significantly affect the composition of 30 days storage of MLSS in the system by a sudden addition of 100 mg/liter carbon based on feed flow. However the fresh carbon may be sufficient to adsorb much of the offending inhibitor and protect the bio-mass.

Phosphorus addition is needed as nutrient for the bacteria. Virgin Nuchar SA-15 carbon contains significant phosphorus, as does the wastewater feed. Make up phosphoric acid is added to maintain a minimum ortho-phosphorus concentration of 0.3 mg/liter in its effluent. In 1979 approximately 80,000 kg. of 35% phosphoric acid were used. This was waste acid from a local industry and therefore significantly cheaper than normal commercial product.

The plant has no need to add nitrogen as there is sufficient ammonia ion in the feed to meet any nutrient needs. As had been seen in laboratory studies, Chambers Works waste is inhibitory toward nitrifying bacteria, and there has been no significant ammonia removal across the plant.

Since startup a polymer has been added to the feed to the secondary clarifiers to improve settling. Until recently a dry cationic polymer was used at a nominal 1 ppm concentration. The plant is now evaluating a dual polymer treatment system using liquid polymers. These polymers being evaluated were selected based on laboratory tests which indicated they might surpass the performance of the single polymer and still cost less. Approximately 5 mg/liter of a cationic polymer is added at the discharge from the aerators. One mg/liter of an anionic polymer is added 1.5 minutes later at the end of the 1.4 m (54") diameter line from the aerator to the flow splitter just before the two clarifiers. After approximately two and one-half months test operation, the TSS in the clarifier overflow have not dropped significantly. However there have been extraneous problems unrelated to the polymer which may have masked any improvement. Even assuming no reduction of TSS in the overflow of the clarifiers, operations so far favors the liquid system because of easier handling, and elimination of a housekeeping problem with the dry powder.

Shift operators have the task of adjusting flows between the two clarifiers to keep the sludge blankets below the overflow weirs. Continuous recording turbidimeters monitor the TSS in the overflow from each clarifier, but they have not always been reliable. Because of the aforementioned problems in wasting solids from the system, there have been many occasions when part of the sludge blanket has been carried over the effluent weir. In such cases the normal procedure is to increase the underflow rate from the offending clarifier. However, most of the time both recycle activated sludge (RAS) pumps have been on at full flow. Under these conditions, underflow from the other clarifier had to be proportionately reduced. If increasing RAS flow did not work, then flow into the clarifier would be cut and more pushed to the other clarifier. Because of differences in sludge blanket levels and, at times, mechanical differences between the clarifiers, the flow split between the two is often unbalanced.

Higher RAS flow appeared to help keep effluent TSS down. Since the clarifiers have been continually overloaded, the plant generally has operated with maximum RAS flow. With both RAS pumps on line this is 90 m^3/min, with a resultant recycle ratio close to one. Immediately after startup, and in the summer of 1978, the plant tried to operate at a 0.5 recycle ratio and use only one RAS pump. Both times there was a significant increase in effluent TSS after about four weeks and two pump operation resumed. However there was always an extraneous factor that could have affected TSS. In late September, 1979, operation with one RAS pump was again attempted. Since then the plant has operated at an approximate 0.5 recycle ratio for over three months. Effluent TSS are still high, but no more so than previously. Both RAS pumps are turned on during periods of very high solids carryover, but the second pump is turned off as soon as the TSS surge subsides. Since September, 1979, the WWTP has operated with one RAS pump over 90% of the time.

Equipment

The three 15,100 m^3 (4,000,000 gal) aerators are each equipped with 1172 Kenics mixers. These static mixers keep the MLSS in suspension as well as transfer oxygen into the liquid for bio-oxidation. Liquid depth is about 6.1 m (20 ft). The mixers are installed on 1.5 m (5 feet) centers in the 56 m (185 ft) diameter tanks. Each mixer is 0.30 m (1 ft) in diameter and 1.5 m (5 ft) in height. Forty three air laterals 7.6 cm (3 in) in diameter supply air to the mixers, the air being released through two 0.95 cm (3/8 in) diameter holes on the underside of the lateral. The air supply system was designed for 9% maximum maldistribution. By visual observation the air was well distributed during initial operation.

The mixers were designed to provide sufficient gas-liquid mass transfer to treat 53,000 kg/day (116,000 lbs/day) of BOD at an air flow of 0.34 m^3/min. (12 cfm) per mixer. Enough blower capacity was provided to deliver an air flow of 0.71 m^3/min., which would handle 100,000 kg/day (220,000 lbs/day) BOD. Oxygen transfer was the controlling design parameter for the mixers. Pilot tests showed that the MLSS, at their expected maximum concentration of 12,500 mg/liter, could be suspended at less than 0.28 m^3/min. (10 cfm) per mixer. At 0.14 m^3/min (5 cfm) the tests showed the MLSS would not be properly suspended.

Contrary to the expectations during design, the factor controlling the minimum allowable air flow has been suspension of MLSS. Because of the low carbon dose, long sludge age mode of operation, the aerators have operated at MLSS levels ranging from 18,000 to 29,000 mg/liter. The BOD load to the WWTP has averaged only 24,000 kg/day (53,600 lbs./day), well under design values. Even allowing for the fact that some materials which do not respond to the laboratory BOD test are oxidized in the PACT process, the oxygen transfer needed in the aerators has been well below their capacity. During the initial 18 months of full-flow operation, there were 3 months when average air flows were less than 0.22 m^3/min. per mixer and oxygen concentrations were still well above the 0.5 mg/liter allowable minimum.

At lower air flows the MLSS appeared well suspended, but a positive correlation was noticed between air flow and DOC removal efficiency. Observations by divers during aerator repairs, which are discussed later, finally confirmed that there is an unagitated 0.3 m to 0.7 m sludge blanket on the bottom of the aerators at normal air flows. The increased DOC removals at higher air flow were caused by an effective increase in sludge age as more MLSS were suspended to react with the feed. Air flow is currently maintained at 0.36 m^3/min. (12.8 cfm) per mixer to assure good solids suspension.

In retrospect, and considering current low BOD levels in the wastewater, it might have been more efficient to forego the enhanced gas-liquid mass transfer obtained with the mixers, and to have operated with bare holes. Solids mixing and suspension would have been improved. Consideration has been given to a plant test in which the mixers would be removed from one aerator.

By November, 1978, the bubble pattern across the aerators was disturbed by areas where bubbles up to one meter in diameter erupted. There were also several areas of diminished bubble activity. It was worse on aerator AE-151, the first one in which the mixers were installed. It was decided to drain that aerator and make repairs before winter. A particular concern was that one or more of the 7.6 cm air laterials had torn loose, and might damage adjacent mixers as it whipped about.

Cleaning the aerator was a massive job. After draining, the aerator had sludge banks of up to 0.7 m in depth throughout its 3180 m^2 area. Adequate provision for cleaning an aerator had not been provided in design. Through experience, a cleaning technique evolved which had operators using fire hoses to sluice sludge into 5 cm diameter suction hoses from a portable pump. It took three weeks to clean sludge from the aerator.

Approximately 25% of the Kenics mixers were found filled with solids. There was good air flow from only 43% of the mixers with most of the flow occurring near the center of the aerator. This was because the 7.6 cm air laterals were partially plugged with solids, particularly towards the closed ends at the tank edges. Support legs had failed on 10% of the mixers, and on 1% the mixer tube itself was broken. On approximately 17% of the mixers the mountings to the aerator floor were loosened. The large air bubbles had been caused by 12 breaks in air laterals. The hold down strap for the mixers had loosened, and mixer movement had caused the strap to saw through the plastic air lateral.

It took approximately seven weeks for repairs, including time to re-design the mixer mountings. Besides repairing all damaged mixers and laterals, the mountings on all mixers were improved. For operating reasons, the aerator was placed back on line in late January before all the mixers had received all the mounting improvements. Most of the mixers were cut off to 0.9 m It was hoped that shorter tubes would improve the suspension of sludge and develop less stress on the foot mountings. Strain gauge measurements during subsequent operation showed no differences in stress on the foot mountings. If there was a penalty in mixing performance with the shorter mixers, it was not evident by gross observation.

Similar repairs were planned for a second aerator (AE-153) in the spring of 1979. Because of the high cost of the AE-151 repairs, over $200,000, an alternate technique was tried with excellent results. In May, 1979, professional divers entered the operating aerator and, guided by radio directions, located breaks in the air laterals by feel. It is impossible to see in the black PACT slurry. The divers stopped leaks in six air laterals with rubber backed clamps. Using a bent rod the divers opened all the plugged 0.95 cm air holes on the underside of the laterals. Sixty six percent of the holes were plugged. As expected, sludge had settled on the floor of the aerator. Underneath the laterals it was about 0.08 m to 0.2 m in depth. Between the laterals it had built up to a depth of 0.3 m to 1.2 m.

The divers also cut badly damaged mixers loose and removed them from the aerator. The total cost of these repairs was less than $10,000. While the repairs were obviously not as extensive as those to AE-151, they have maintained AE-153 in good operating condition. Because of the excess gas/liquid transfer capacity there is no noticeable drop in aerator performance with a substantial number of mixers inoperable. To test the effect of the mixers on fluidization of sludge, the divers removed a group of seven mixers from AE-153. They reinspected the area five days later. There was no sludge on the bottom of the aerator, confirming that the mixers do hinder sludge circulation.

Samples were taken of the crusty material plugging the air lateral holes. It was 60% calcium carbonate. Primary effluent is high in calcium salts, as during primary treatment from 70,000 to 230,000 kg/day of acid (as $CaCO_3$ equivalent) is neutralized with lime. Calculations show that the humidity of the inlet air is low enough to evaporate water at the edge of the hole, leaving behind a carbonate precipitate. A proposal to humidify the air is being considered but a substantial water flow rate would be needed. The plugged holes have a significant effect on the air blowers. Before cleaning, the main air valve to AE-153 was 100% open. After unplugging the holes, the valve was only 20% open at 420 to 450 m^3/min. of air flow to AE-153.

AE-151, which had been repaired four months earlier, was entered and inspected while in operation. There was a relatively uniform 0.5 m layer of sludge on the bottom except for one quadrant where the sludge was 0.7 m to 1.0 m deep. About 12% of the AE-151 mixers were spot checked. Of these, 7% had both air holes plugged and 8.5% had one hole plugged. AE-152 was also checked and found to have the same general sludge depth as 151. Ten percent of the mixers were spot checked and 56% had both holes plugged while another 20% had one hole plugged. No repairs were made at that time. Water temperatures in the aerator were about 30°C, and where sludge was packed around an air lateral the divers claimed that the temperature was as high as 60°C. This caused heat stress.

The third aerator, AE-152, was repaired by divers in November, 1979. The repairs were essentially the same as were done on AE-153. Current plans are to eschew any major repair as were done on AE-151, until absolutely necessary, and to continue to use divers to unplug holes and repair air laterals at six month intervals.

Air is supplied to the aerators by five, 4-stage, 1,000 HP, 500 m^3/min. (17,600 cfm) blowers. There was some initial concern because the manufacturer previously had made only one machine as large as these. Two of the five blowers needed major repairs at start-up. Since then they have run well, met design specifications, and have been gratifyingly quiet in operation. There were problems with shutdown instrumentation which caused shaft damage to three of the blowers, but a change in instrumentation eliminated this problem.

The main problem with the secondary clarifiers has been that they are overloaded. However there were some mechanical problems which contributed to diminished performance. Surface scum on the clarifiers contributes to high effluent TSS. As installed, the scum removal system did not work well. Successful modifications were made, the chief of which was raising the gates on the center flocculator section of the clarifiers above the water surface. This forced foam and scum to flow under water and beneath a baffle to reach the outer annular area leading to the overflow weir. As installed, there was too short a distance between the bottom of the center flocculator ring and the floor of the clarifiers. The rings were raised, but there was a 0.7 m difference between the two clarifiers. Until corrected in December 1977, it was difficult to balance flow between the clarifiers. The depth beneath the flocculator ring is now 2.4 m in both clarifiers.

To minimize the loading per linear foot of the clarifier overflow weir, the circumferential weir was two sided. Overflow ran into a center trough and then to the discharge line. There was a narrow space, 0.30 m., between the clarifier wall and outer edge of the weir trough. There was high, upward liquid velocity through this space which entrained solids. After one year of operation, the outer edge of the weir was raised so all flow went over the inner edge. This seemed to improve clarifier performance.

In winter weather there have been problems with the rim drives for the clarifier bridges. The rubber driving wheel slips when ice or snow collects on the rim of the clarifier, this quickly stalls the bridge and the drive motor kicks out. Studded snow tires have helped, but the problem has not been entirely corrected. The plant is now experimenting with special non-skid coatings and heat lamps on the drive unit.

In 1978, the motors on some of the flocculators in the clarifiers (there are three on each) failed. As there was no significant change in effluent TSS, all the flocculators were turned off as an energy savings measure.

A 0.61 m (24") diameter steel pipe carries underflow from each clarifier into a 1.2 m (48") line to the RAS flow splitter. In January, 1978, in December, 1978, and in July, 1979, a section of 0.61 m line sprang a sudden leak. In the latter two instances the leaks were severe. In all cases a temporary wrapping around the line restricted flow enough for sludge to accumulate and stop the leak. A metal jacket was then welded onto the pipe over the failed area.The butterfly valve on one underflow line had also stopped working by the end of 1978. The control rod on one steel valve was found eroded away, and both valve discs were severely eroded. The underflow valves have now been replaced by rubber pinch valves. In an eight hour shutdown during the summer of 1979 all RAS piping was inspected internally. Most of the piping was in good shape, except for steel sections where slurry velocity was high and changing direction, or where there were poor welds. Such sections have been replaced with stainless steel.

Two 45 m^3/min. (12,000 gpm) spiralift (screw) pumps return RAS to the aerators via a flowsplitter. These pumps have performed adequately. On both pumps it has been necessary to replace the bottom, underwater bearings twice and the upper bearing once. There were also initial problems with an anti-reverse ratchet which have since been solved. Keeping grease in the bearings has not been straightforward, and some modifications to the manufacturer's procedures were necessary.

Virgin activated carbon usage is 4,500,000 to 2,700,00 kg/year (10 MM to 6 MM lbs./year). This scale of operation dictates railroad car delivery of carbon. To minimize housekeeping problems the carbon is slurried in water as soon as possible. Three 227 m^3 (60,000 gal.) agitated, slurry storage tanks are available. Design data specified a slurry concentration of 0.12 kg/liter (1 lb./gal.), but the tanks and pumping system have handled slurry concentrations over 0.25 kg/liter easily.

A vacuum unloading system is used. Before startup, a change in the type of carbon car to be used required development of an unloading adapter for the vendor's hopper cars. The original system consisted of vacuum blower downstream of a pulse jet cleaned bag filter. Carbon was sucked from the car into the filter. It then dropped into a screw conveyor through a rotary air lock, which maintained negative pressure in the filter receiver. The screw conveyor transfers the carbon to either of two storage tanks. The system unloaded 6,400 kg/hour of carbon, which was design specification.

While the system moved carbon well, there was a severe carbon dusting problem. Unless unloading rate was controlled very carefully, which required an unrealistic amount of operator attention, carbon dust was sucked through the filter bags and into the blower. From there the fine, black powder sprayed throughout the area. A satisfactory unloading system was developed during the first year of operation. The carbon first goes through a cyclone separator which drops it into the air lock. Off-gas from the cyclone passes through a bag filter and then a water scrubber before it reaches blower suction.

There have been problems with the valves used in carbon slurry service. The "Teflon" ball valves originally installed did not score badly as had been feared. However they were almost impossible to operate at times. Powdered carbon packed between the ball and seat and jammed the valve. Pinch type valves that may be more suitable for this service are being tested.

The WWTP is very heavily instrumented. As designed the PACT system included continuous recording instruments to measure aerator dissolved oxygen (DO), inlet and effluent DOC, turbidity or TSS in clarifier overflows, and a bio-monitoring device to monitor the feed to the primary section of the WWTP for potential toxicity. The latter instrument automatically compared oxygen uptake of a sample from the aerator with a sample of feed. It required an excessive amount of technical attention. In mid-1978 the instrument was disconnected.

The most important measurements for the process operator are aerator DO and feed and effluent DOC. The original DO probes were not as accurate as desired in the 0-5 mg/liter range. They were replaced with a different type unit which has an agitated measurement chamber. With this type probe an accuracy of 0.1 mg/liter is obtained even below 5 mg/liter total concentration. The new units as bought required 8 to 10 hours per week of instrument mechanic time. Homemade modifications have reduced this to about one man hour per week.

The continuous DOC analyzers have been high maintenance items. Per week, each analyzer consumes eight hours of instrument mechanic time and five hours of technician time. This includes a daily calibration. Preparing the semi-continuous sample for analysis is a problem. The cartridge filters, which remove suspended solids, need frequent changing. Further, the filters on the effluent analyzer are easily overloaded by high TSS in the effluent. Some of the carbon fines carry through to the analyzer, give false high DOC readings, and throw off instrument calibration. Work in progress includes an evaluation of alternate analyzers and tests of a continuous belt filter for sample filtration.

The original turbidity analyzers, which utilized reflected light to measure surface scattering, were unsatisfactory as they responded to changes in effluent color as well as TSS. Within six months of start-up they were replaced with units which use a laser beam to measure suspended solids. These units have been reliable and normally require only one hour/week of attention. However, since the middle of 1979 there have been quality problems with the laser units the instrument manufacturer uses. The lasers have been failing within a few weeks and replacements are not always available. This should be a temporary situation.

SOLIDS TRAIN (SLUDGE THICKENER, PACT FILTER PRESS, SLUDGE CONVEYORS, REGENERATION FURNACE)

Performance

The most significant operating result is the demonstration that powdered activated carbon can be regenerated, at good yield and reasonable quality, from PACT sludge in a countercurrent multiple hearth regeneration furnace. With the aid of a post-regeneration acid wash, the carbon can be regenerated several times with no build up of ash or other impurities which could harm performance. A second important result is the demonstration of improved sludge filtration because of the presence of carbon. A sharp drop in sludge filterability is apparent when the powdered carbon content of PACT sludge drops below 50%.

Overall performance of the solids train has been below design because of serious capacity limitations in the sludge conveying system and the PACT filter press; the latter not withstanding the relatively good filtration properties of PACT sludge vs. normal activated sludge. The sludge thickener has performed above design expectations, but has not really been needed because of the high MLSS concentration available in the RAS stream. Because of limitations on sludge delivery to the furnace, there has never been an opportunity to run the furnace at a steady, high rate to properly assess its capacity. However, certain parts of the furnace, such as the product quench tank, have been shown to need modification to achieve design rates.

Because of the solids train capacity problems, operation of the regeneration furnace has approximated only a break even proposition. However, there is no assurance that the alternative, using carbon on a once through, "throw away" basis could be cost effective for very long, even at low dose operation. Steady tightening of restrictions on disposal of aerator waste sludges, especially when they are contaminated with chemicals, are raising the cost of disposal. Eventually this might preclude anything other than incineration of wasted sludge.

Reasonably consistent, but below expected design, operation of the regeneration furnace commenced February, 1978. In the 23 months from February, 1978 thru December, 1979, the regeneration furnace operated at 55% intime; intime being defined as sludge being fed to the furnace. This period includes two hearth failures, approximately 10 months apart. Each failure required a complete furnace cool down. After the first failure, hearths #4 and #3 had to be rebuilt. After the second failure, hearths #2, #3, and #4 had to be rebuilt. The rebuilds took five and one-half and nine weeks respectively from failure to restart of sludge feed. Exclusive of hearth rebuilding, and one cold shutdown in July, 1979 for a rabble arm repair, furnace intime has averaged 66%. However over one-half of the downtime has been caused by failures of the feed system rather than the furnace itself.

While operating, the furnace has produced regenerated carbon with an average iodine number of 480. This is approximately 63% of the IN value of the mixed carbon fed to the furnace. In these 23 months of operation, 4,100,000 kg. of regenerated carbon have been produced. The yield based on carbon fed to the furnace is estimated at 80%. This is calculated from a 23 month solids balance across the liquid train*. Part of this calculation is a deduced factor of 0.26 kg bio-mass + adsorbed organics generated per kg of DOC fed to the aerators. The

*A direct calculation of yield across the carbon regeneration furnace is difficult. It is hard to determine the true fraction of activated carbon in the PACT sludge which is fed to the furnace. Conventional thermal analytical techniques cannot separate the adsorbed organics and bio-mass on the carbon from volatiles, usually 10% to 20% by weight, that were originally present in the activated carbon feed. This means there is no reliable number for the weight of activated carbon fed to the furnace. Without such a number it is impossible to calculate a yield. In an attempt to circumvent this problem, furnace yields were calculated on a "fixed" carbon basis. "Fixed" carbon is defined as the solids present exclusive of ash and volatiles. Theoretically thermal analysis could accurately determine the fraction of "fixed" carbon in the PACT sludge feed to the furnace. However "fixed" carbon yields across the regeneration furnace determined by these methods were unrealistically low, approximately 60%. The "fixed" carbon content of the product regenerated carbon could be determined accurately. However the analysis for volatiles in the sludge feed gave low results. This made the calculated weight of "fixed" carbon fed to the furnace too high; and hence the calculated furnace yield too low.

calculated average activated carbon content in the feed sludge was 56 to 59 weight percent. Calculated yields over shorter time periods, such as one month, are not reliable because of errors introduced in the solids balance by changes in the inventory of solids in the aerators and clarifiers.

After acid washing, the average ash and volatile levels of the carbon have been 20% and 8.8% respectively (for comparison, note that the virgin carbon as purchased will contain from 4% to 30% ash and 10% to 20% volatiles). Average feed rate while running has been 2,240 kg./hr. wet sludge. There have been significant periods of time when performance has been better than these averages. Table 6 summarizes furnace performance during periods of relatively good operation. Design feed rate to the furnace has been attained once, for one 48 hour period in November, 1979.

TABLE 6. REGENERATION FURNACE PERFORMANCE

	Time Period			
	Feb.'78 thru Dec.'79	June '79	March '78	Design Values
Reg. Carbon Produced, kg/day	5860	7000	9600	18,200
Kg Reg.Carbon/ kg dry feed	.45	.50	.46	.48
Carbon Yield	80%	Not Available	Not Available	70%
Est. Quality Recovery	63%	70%	63%	75%
Regenerated Carbon IN	475	537	487	560
Regenerated Carbon % Volatiles*	8.5	8.6	7.2	8
Reg. Carbon % Ash	18.4	16.7	15.4	15
Furnace In Time	55%	69%	79%	90%
Wet Sludge Feed Rate While Operating, kg/hr.	2240	1940	2440	4190
Sludge Feed % Solids	44	44	44	38
Dry Solids Fed, kg/day	14,900	13,900	20,800	34,300
Regenerated Carbon Produced While Operating, kg/hr.	443	421	506	1,770

*Volatiles equal weight loss when carbon is heated to 950°C at a controlled rate of temperature rise with minimum exposure to air. Total heating time equals 5 minutes.

Heat is generated in the furnace from burning bio-mass and adsorbed organics; however, this is not sufficient to evaporate all the water in the sludge feed. Some of the heat to the furnace must be supplied by the oil burner. During design it was assumed that burner output would be the limiting factor in furnace capacity. This has not been the case.

It was assumed the filtered sludge feed to the furnace would average 38% solids; in fact, it has averaged 44% solids. Further, the total feed rate has been less than one-half design values. Even if feed rate were not limited by the press and conveyor systems, less than design furnace capacity would have been needed because of the low carbon dose, long sludge age mode of operation now used. Known capacity limitations to the furnace are getting sludge into it through the 30.5 cm x 30.5 cm (12 in. square) gatelock feeder, and removing the hot carbon via the water quench tank at the bottom of the furnace. No. 2 fuel oil usage has averaged approximately 0.19 m^3/hr. (50 gal./hr.) while the furnace is at temperature.

There have no problems with the acid washing system for regenerated carbon slurry. Slurry piping and pump modifications have been made based on operating experience to assure washing system capacity will not restrict furnace performance. Acid washing does not have to run continuously. It has been shut down for several days before ash began to build to excessive levels in the carbon. Table 6 gave carbon properties after acid washing. The slurried carbon fed to the acid wash tank has averaged 26% ash. While the acid washing system was operating, the carbon was treated with an average of 0.8 kg of HCl (100% basis)/kg of ash. This removed approximately 30% of the inlet ash.

Because of sampling problems and inconsistent furnace operation, the split in carbon yield loss between that which is burned on the lower furnace hearths, and that which is blown out of the furnace with the off gas, has not been satisfactorily determined. In the latter case the carbon is either caught in the water scrubber and recycled to the quench tank or carried through the scrubber to the afterburner. Carbon recycled via the scrubber may be of poor quality if it has originated on one of the upper hearths, and therefore is not completely regenerated. In that case it hurts quality yield when it is mixed with normal product.

The afterburner does its job of destroying all noxious gases and particulates released by the furnace scrubbers. As long as the afterburner temperature is properly controlled, the furnace operates with a clean, odor free stack which meets all local air quality restrictions.

The performance of the conveying system has been poor. Operating utility of the conveyor system itself has been approximately 80%. One problem is that the system comprises six separate conveyors in series. There is an installed spare for only one of the six; a project for an installed spare for two more of the six was scheduled for completion early in 1980. Figure 13 shows the conveying system. The most important factor affecting utility is mechanical wear. After complete rebuilding of the system in December, 1978 and January, 1979, it operated relatively well for about three months. However, by September, 1979 CY-282 was on the verge of complete mechanical failure and was replaced. Other major modifications were made prior to January, 1978.

When the conveyors are in good mechanical shape, capacity is limited by plugging at the gatelock feeders on top of the furnace. Plugging tendency is a function of filter cake quality. Conveyor utility has also been hurt by tramp material which gets into the bunker conveyor (CY-281) under the press and ultimately jams one of the six conveyors.

After severe problems during startup, in-time of the PACT filter press has averaged about 85% since January, 1978. The main causes of lost time have been 16-hour high pressure water washings ("hydroblitzing") every week to ten days, numerous shutdowns for periodic replacement of individual cloths, plate gaskets, and staybosses which attach the cloth to the plate, and high pressure feed pump(s) outages. The latter problem has been somewhat ameliorated by replacing the original four, parallel, single cylinder piston pumps with one triplex, higher capacity piston pump.

Filter cake quality in terms of percent solids has exceeded design. It averages 44% vs. a 38% design value. However, there is a surprising variation in cake quality within a very narrow range of solids concentration. Depending on composition of the MLSS, a greater than 40% solids cake can either be an easily handled, friable cake, or a material reminiscent of bubble gum and a nightmare to convey.

A more serious problem than mechanical difficulties has been the long filtration cycle times. They can vary from 1.5 to 7 hours depending on sludge composition and filter cloth condition. When carbon dose is over 100 mg/liter, cycles average between two and three hours, at lower carbon dose they average about four hours. This compares to a design estimate of approximately one hour cycles. Specific resistance measurements on plant sludge show, that at times when its filtration properties are no worse than design values, press cycle time is still much longer than expected. The calculations of cycle time were simply overly optimistic.

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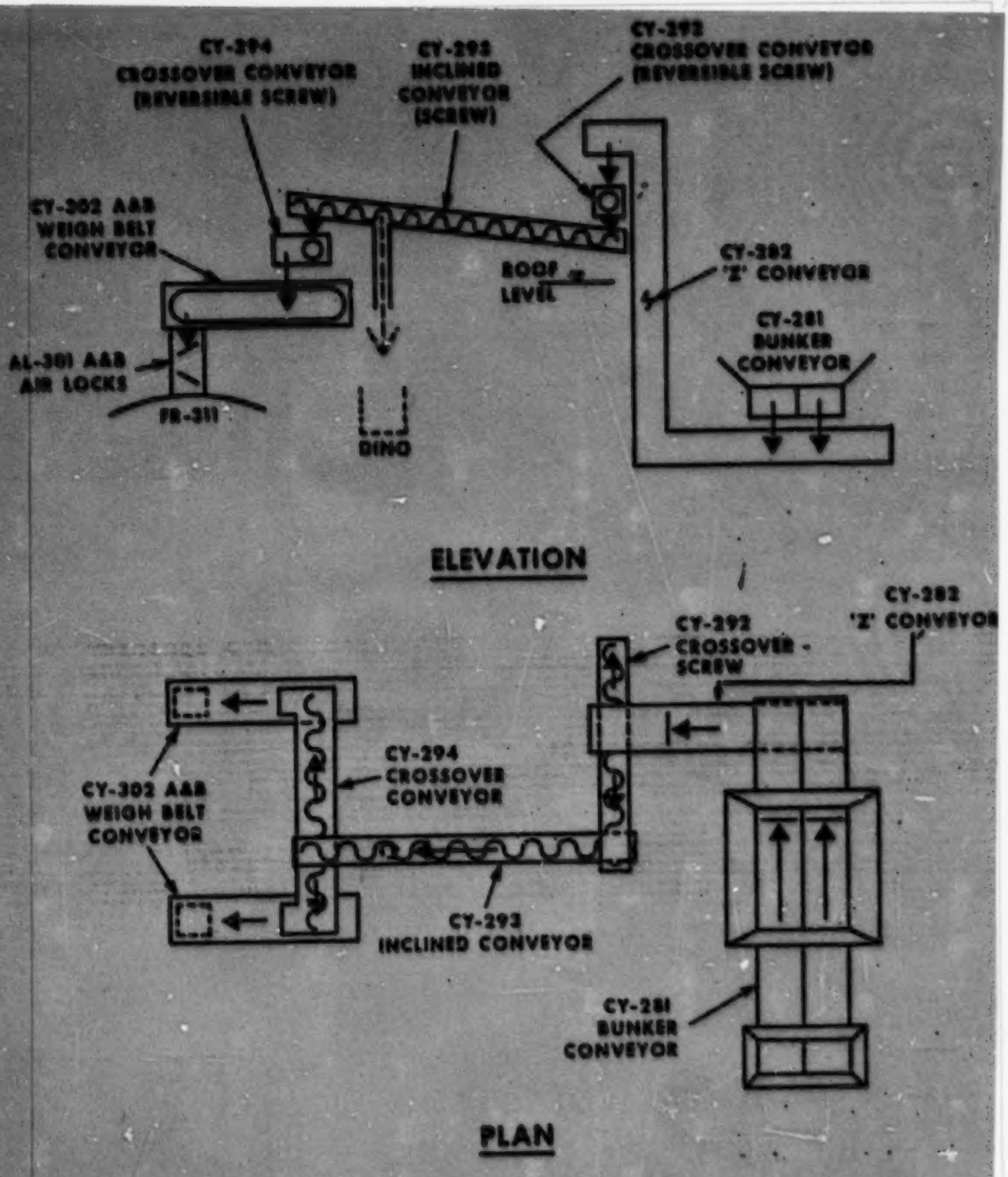
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Figure 13. Schematic of current sludge handling conveyor system.

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Also, however, the carbon concentration of the PACT sludge has never been as high as forecast.

The 227 m^3 (60,000 gal.) sludge thickener has consistently delivered a 7-10 wt.% slurry for feed to the PACT filter press. No addition of polymer is necessary. In fact, if not controlled properly, the thickener has delivered a slurry as high as 20 wt.% which promptly plugged the slurry pumps. Because of a tendency for the original pumps to plug, they were replaced with larger units of a modified construction which have worked well. Because the thickener has worked as well as it has, sludge is wasted directly from the aerators instead of from the more concentrated RAS stream.

Operating Strategy

Since January, 1978, operating strategy has been to run the solids train at as high a rate as possible. Generally this has not been enough to equal the rate of solids added to the system, and the liquid train periodically purges itself via an overflow of TSS from the secondary clarifiers. Several steps have been taken to improve solids train production.

To maintain sludge wastage from the aerators when the regeneration furnace is out of service, filtered sludge is dumped to a "dinosaur" or "dino", a 26.2 m^3, 20,000 kg payload (34.2 yd^3, 43,800 lb. payload) container, and hauled to a storage area for future carbon recovery. An inventory of sludge is also vital to maintaining feed to the furnace during filter press outages. Current operating strategy calls for keeping some stored sludge available at all times.

Several measures have been taken to improve production from the filter press. During press outages sludge was held in the thickener where it could go "stale", that is its specific resistance to filtration would increase. Procedures have been changed so that underflow from the thickener is continuously recycled to the aerators when it is not being pumped to the filter press feed tank. This assures fresh sludge feed to the press.

Precoat is used before each press cycle. Studies have demonstrated its need, but there have not been any major improvements in press performance by varying precoat types and quantity. A cellulosic type material is preferred as it ultimately reaches the furnace. Tests have recently been made of direct addition of a polymer to the sludge to improve filterability. No major improvement has been seen, but the equipment arrangement has required that the polymer be added on the suction side of the high pressure feed pump(s). Shear in the pump or a high pressure recirculation line, can ruin the polymer's effectiveness. Further work is planned. Laboratory tests have shown that an admix could significantly improve filtration. Permanent facilities for this would be quite expensive for a plant of this size and as yet there is not enough justification to prepare a project. A plant test with temporary equipment is a significant undertaking, but one may be scheduled in 1980.

While the effects of certain operating parameters on PACT sludge filtration are relatively well defined, there are still unexplained differences in filter press performance from cycle to cycle and day to day. Cycles times have varied from two to four hours with similar sludge feed and equivalent press conditions. Further technical work on this problem is scheduled.

With successive filtrations, filter cloths become steadily more blinded and the press finally must be shut down for cleaning. High pressure water sprays are used to blast sludge from the interstices of the cloth. The timing for hydroblitzing is based on the current length of filter cycles, and the utility situation of feed pumps and downstream equipment. Frequency of cleaning varies from twice each week to once every three weeks depending on sludge condition. A thorough cleaning will require over 16 hours. Approximately once/year it has been necessary to completely re-dress the filter press. Complete replacement of filter cloths, gaskets, and padduck costs $13,000 and takes two weeks. The underscreens cost $56,000 and may need replacement every two years. There has been some success in finding cheaper materials and better installation techniques, but re-dressing will continue to be a large, costly job.

The length of a press cycle is controlled by filtrate flow rate. As the cycle progresses, feed pressure increases and filtrate rate drops as solids pack more tightly into the press cavities. At a specified filtrate rate the operators are instructed to end the cycle and drop the press cake. When a cycle is continued to the proper filtrate rate, the cake will handle as a reasonably dry cake. If cycles are arbitrarily shortened the cake will be very wet and sloppy in appearance and it will have to be scraped off the cloths. However, the percent solids will normally still be over 40%. Because the furnace has not been limited by heat input, there is an incentive to shorten press cycles to increase output. However, sloppy cakes do not convey well, particularly in the screw conveyor, CY-293, and so shortening press cycles can be self-defeating. Materials, such as wood flour, have been added to filter cake in the bunker conveyor, CY-281, to improve handling. Some minor improvement has been seen, but not enough to allow significantly shorter press cycles.

Prior to the Fall of 1979 it was necessary to hydroblitz the filter press or increase carbon dose to improve filterability when press cycles exceeded three hours. Longer cycles than this, on top of normal mechanical outages, did not permit adequate sludge wasting rates. During 1979 it became obvious that the plant could operate for an extended period of time at carbon doses less than 100 ppm. The cost penalty for maintaining dose artificially high to improve sludge filtration was over $50,000/month. This justified piping and instrumentation modifications so that one of the primary treatment filter presses (FP-76) could be used simultaneously in PACT sludge service with the regular PACT press, FP-277. FP-76 had originally been designed as a "swing" press for use in secondary/tertiary service instead of FP-277, when FP-277 was out of service. With two presses available to filter PACT sludge, cycle times well over four hours can be accepted. Adequate sludge removal from the aerators can be sustained while allowing sludge specific resistance to rise to several times former, normal levels.

Operating strategy for the conveyor system has been to upgrade the equipment mechanically as much as possible. There are now parallel units at two points in the six conveyor system. Parallel units for two more of the steps were scheduled for installation early in 1980.

Some conveyor capacity increase is expected when a parallel, drag flite conveyor to screw conveyor CY-293 is in service. The screw kneads sloppy sludge into large gum balls which plug the gatelocks on top of the furnace. Screw conveying seems inherently unsuitable for PACT sludge, particularly in light of the large variation in rheological properties under normal operation. Ultimately the gatelocks will be modified so they can transfer wet, sticky sludge, or they will be replaced.

In retrospect, it appears that the filters should have been located above the regeneration furnace; or the filter and furnace located horizontally far enough apart that an inclined belt conveyor could have been used to transport sludge. Although not devoid of problems, PACT solids move very well in slurry form when using proper piping, valves, and pumps. It would have been much easier to pump slurry 15 meters up to a filtration unit than to drag filter cake the same distance. The carbon cake is erosive and seriously wears metal dragging equipment.

Furnace operating options are very limited because of a strong interdependence among operating conditions. Operating instructions specify an acceptable temperature range for each of the five hearths. Unfortunately, actions which bring the temperature of one hearth into range can drive another hearth's temperature out of limits. Hearths # 2 thru # 5 (# 1 is the top hearth) have independently controlled, air injection nozzles to control temperature without changing the hot gas flow from the combustion chamber. However, the temperature control available from air injection is not always enough.

The furnace must operate under reducing conditions with water vapor present to regenerate the carbon. In lieu of direct addition of steam, a portion of the 100% relative humidity off gas from the scrubbing system is recycled back to the combustion chamber. It is now felt that higher water concentrations than are presently obtainable are needed to improve the quality of regenerated carbon. Facilities for direct steam addition have been installed, and tests are scheduled in 1980. A problem with this change, and furnace operation in general, is insuring that explosive CO and H_2 mixtures do not develop in the furnace from the water gas reaction. This concern has justified extensive theoretical calculations, and there is a continuing program of gas analyses. Further studies along this line are scheduled in 1980. While there is a reassuring background of years of industrial operation of multiple hearth furnaces to regenerate granular carbon, the fact that this system is treating powdered carbon is reason for caution.

Other variables being constant, laboratory studies have shown that quality is generally obtained at the expense of yield, and that better quality is achieved at higher temperature. During the past year the tendency has been to try to operate the upper hearths on the high side of the allowable temperature range. Upper hearth temperatures are often limited by the high temperature limits on the bottom hearths. These restrict the allowable heat input from the burner. Therefore, the furnace operator does not have complete control over the hearth temperature profile. The profile is also very dependent on the sludge feed rate, which is a strong function of filter cake quality.

The afterburner has normally operated at approximately 650°C and performed well. There were occasions when the stack discharged visible smoke. Recently the stack has been operated 100°C hotter, and plumes have disappeared.

Equipment Experience

The sludge thickener has worked as designed, and no mechanical modifications have been necessary. The original slurry underflow pumps were not capable of handling thicker slurries. They were replaced with larger, rubber lined pumps which have been satisfactory.

The filter press (FP-277) is highly automated, and its instrumentation had to be compatible with the complex control sytem for the two adjacent primary presses. One of the two primary presses, FP-76, was designed to operate as a "swing" press in PACT service when FP-277 was down for extended periods. The advantages of automated operation are accompanied by a requirement for skilled electricians and instrument mechanics to maintain the press. Before start up, several modifications were made to the hydraulic closure system based on experience with the primary filter presses.

Initial filter press operation was good, but after about 45 cycles, holes appeared in the nylon cloths. The problem, which was unique to the PACT press, grew progressively worse and required a technical study. A variety of cloth types, including polypropylene and stainless steel, were tested. Different weaves were tested. Different types of underscreen with different surface treatments were tried. While there were advantages and disadvantages to each type, a change in underscreen or filter cloth did not solve the problems. The possibility of chemical and/or biological degradation was explored. Neither was a factor.

Observations made over several months showed a higher probability of holes forming near raised portions of the underscreen. It became obvious that mechanical stresses on the cloth contributed to the problem. Various types of soft padduck were installed under the cloths and the frequency of holes dropped by two thirds. A padduck cloth is now routinely used in the press.

The difference in performance between the PACT and primary filter presses implicated powdered carbon as a major factor in hole formation. Filtrate velocity through the cloth is very high at the beginning of a press cycle. Once a hole begins, the abrasive carbon particles must progressively enlarge it as they are blasted through the cloth. In October, 1978 the equalization tank was taken out of service. This moderated initial filtrate velocity. Since this change the frequency of cloth holes has again dropped by two thirds. Since October, 1978 approximately four to eight cloths have been replaced monthly. This does not include an approximately annual re-dressing during which all cloths are changed.

From October, 1978 thru May, 1979, the filter press availability was just over 90%. Availability has dropped off somewhat since then because of operation at lower carbon dose. This makes it more difficult to filter sludge and requires more frequent filter cloth washings.

The operating utility of the five parallel, high pressure feed pumps was low, and they were high maintenance cost items. In March, 1979, one was removed to make room for a single, large, triplex feed pump. The new pump has been a significant improvement. The new pump has suffered from erosive wear of ball check valves and seats. The original parts have been replaced with ones of more erosion resistant material; this appears to have solved the problem. The new pump's hydraulic drive does not have a wide enough range to control at the high flow rates at the beginning of a cycle and the much lower flow rates at the end. Since the pump could not be operated slow enough to avoid overpressuring the system at the end of a cycle, a bypass line was installed around the press and back to the feed tank. Shear in the bypass valve may hurt sludge specific resistance. This is now being investigated.

All conveyors have suffered from the erosive properties of PACT sludge. The bunker conveyor (CY-281) under the filter press has undergone several major revisions. The variable speed hydraulic drive has been modified and the drive sprockets, chain, and flites have all been upgraded. When CY-281 was first put in service, sludge built up at the discharge end and bridged across the discharge hole. Adjustable baffles were installed to keep the sludge moving along the bottom of the conveyor. The conveyor holds three press drops; each drop is 5700 kg. of wet sludge.

CY-281 originally discharged to a "Z" configuration drag flite conveyor (CY-282). To reduce strain on the drive mechanism, in December, 1977 the upper, almost horizontal section was removed, leaving an "L" configuration. The hydraulic drive had been changed, and many flites had been replaced. In November, 1978 there was a major failure of CY-282. During re-building new and stronger chain, flites, sprockets, guide rails, and traction wheels were installed. By mid-1979 parts of the conveyor which were exposed to sludge were badly worn. In September, 1979 a new, even heavier duty, conveyor with a modified drive and drag system was installed. Since startup the new conveyor has performed well, but it has not been in service long enough to predict its service life.

When the top section of the original "Z" shaped CY-282 was removed in December, 1977, it was replaced with an inclined screw conveyor 24.4 m in length, CY-293. This unit too has suffered erosive wear and has required some major re-buildings. A parallel drag flite conveyor to CY-293 was to be installed in February, 1980.

The weigh belt conveyors (CY-301A&B) have undergone extensive development. Their only current problem is dropping the sludge through the 930 cm^2 opening in the top of the furnace. When the sludge is not sticky and an even feed rate can be maintained, the conveyor system and gatelocks can move wet sludge at the design rate of 4,550 kg./hr. (10,000 lbs./hr.) This rate has been demonstrated once for a 48 hour period. However, operating experience to date has shown sludge quality is not consistent. SLudge of certain consistency is kneaded into large sticky balls in the screw conveyor; and these balls plug the gatelocks. Work has been started on enlarging the gatelocks.

The current double flap gatelocks are designed to minimize air leakage into the furnace. So long as furnace off gas is recycled to the combustion chamber, any air leakage into the top of the furnace will ultimately raise oxygen concentration on the bottom hearths. At times it is impossible to run the lower hearths at as low an oxygen concentration as desired. An advantage to direct steam addition to the combustion chambers is that recycle gas is no longer needed for cooling and water addition. This would end concerns about air leakage at the gatelocks and simplify their modification.

The most eventful furnace experience has been three separate hearth collapses in less than three years operation. The initial failure in April, 1977, of # 3 and # 4 hearths, after less than one month's operation, can be written off as a product of design and construction errors. It was not representative of normal operation. A variety of factors contributed to that failure. During the subsequent six months of re-building, numerous mechanical and instrument control system changes were made to assure steadier furnace operation; and to eliminate operating conditions conducive to hearth failure. Included were rebuilding of all the suspended hearths, # 1 thru # 4, with better quality brick; modifications to the burner to provide a low heat mode of operation; better controls for furnace vacuum; change in position and addition of thermocouples to better monitor gas temperatures at the hearths; putting tighter temperature limits in the operating instructions; addition of the parallel weigh belt feeder (CY-301B) to assure continuity of feed; increasing the size of the inlet grate over the product quench tank to reduce plugging; and a change in insulation of the skewbands. The latter encircle the shell of the furnace at each hearth and maintain compression on the hearth by exerting an inward force against the furnace.

After these modifications the furnace operated intermittently until February, 1978. It then remained at operating temperature until December, 1978 when hearth # 4 failed. During the subsequent 40 day cold shutdown, hearths # 3 and # 4 were rebuilt. After a mid-January, 1979 start-up the furnace operated for 10-1/2 months until hearth # 4 collapsed. In the subsequent nine week shutdown, hearths 2, 3, and 4 were rebuilt with a steeper slope. It is anticipated that this will prolong hearth life by six to twelve months.

There was one other cold shutdown in 1979. In July a drop chute fell and damaged the rabble arm on the hearth below. The necessary repairs could not be made while the furnace was hot.

The inability to maintain a constant feed is a major factor in the hearth life of the Chambers Works furnace. Interruption of feed causes temperature excursions on the hearths which can exceed 40°C/hour, and carry hearths above maximum desired temperature. The normal result of feed loss is an increase in upper hearth temperatures because of the loss of water in the filter cake. With stored sludge available throughout 1979 the conditions which interrupted feed were conveyor outages and maintenance on the furnace itself. Exclusive of furnace downtime for hearth re-building, the conveyors have been responsible for about 20%, or over one-half of the "no-feed" time.

Other negative factors toward hearth life are a potentially corrosive atmosphere in the furnace, and the relatively large furnace cross sectional area which must be spanned by the hearths. Hearth life is shortened by higher temperature as witnessed by the cooler # 2 hearth surviving for almost two years.

There have been other, less serious maintenance problems with the furnace. Both the recycle and induced draft fans have relatively short lives between overhauls, approximately three weeks. They are susceptible to corrosion and erosion. Carbon deposits on the blades unbalance the high speed fans and cause bearing wear. Some progress has been made using alternate materials of construction. It has been difficult to keep control valves operating freely in gas and slurry service around the furnace. Again, changes in valve types are steadily improving the situation.

The hangers for the special drop chutes on the # 2 and # 4 hearth rabble arms have failed more than once. The worst thing that can be done to a hearth is to cool the furnace to ambient temperature and then re-heat it. Therefore, equipment was purchased to remove and replace the drop chutes while the furnace is hot. Several modifications were necessary to make this tool work, but the capability now has been developed to replace chutes without cooling the furnace. On two occasions chutes have dropped and caused damage to the rabble arms on the hearth below. During the last shutdown new and stronger hangers were installed. Because of a previous hanger failure the furnace operated without drop chutes from July, 1979 until the December, 1979 hearth failure. Performance was not as good as had been seen earlier, but it is not conclusive that lack of drop chutes was the cause.

In an attempt to assure proper furnace operation and eliminate operator errors, the furnace was very heavily interlocked. Experience has shown that it is over-interlocked. The large amount of instrumentation defeats its purpose of maintaining steady furnace operation. Failure of some peripheral instrument, unrelated to any real problem with the furnace, is likely to shut the furnace down via an interlock. During upset situations interlocks often hinder re-establishing normal operating conditions by delaying corrective actions until some furnace condition returns to a value which releases the interlock.

The afterburner has not seriously hindered furnace operation. It would be a relatively maintenance free item had it not been installed firing directly up the stack. In this position it catches any slag and debris dropping from the stack walls; and it is subjected to acid rain if it shuts down and the highly humidified off gas condenses on the stack walls.

There have been two significant safety incidents involving the furnace. In violation of normal practice an operator tried to clean the grate above the quench tank without shutting down the centershaft. As the grate was cleaned, a pile of accumulated hot carbon was pushed into the quench tank. There was insufficient water in the quench tank to cool the mass of carbon, and steam erupted up through the grate. A fireball of hot gas was blown out through the open hearth door, narrowly missing the operator. Operating procedures now have been changed so the centershaft must be locked out before any hot work may be attempted on the furnace.

As part of the general interlock system, the belt conveyors, CY-301A or B, normally shut down automatically whenever a furnace interlock is triggered. As has been mentioned , when feed stops the top hearth gets very hot since the inventory of carbon on the hearth burns without any cooling effect from wet sludge. With the weigh belt stationary, the portion above the gatelocks is heated by escaping hot gas. On two occasions the rubber belt caught fire. Instrument logic had to be changed to keep the weigh belts turning when the furnace was down.

START-UP EXPERIENCE

Biological seeding of the first aerator started on November 19, 1976. Prior to this the hydraulics of liquid train were tested using effluent from primary treatment. That section of the WWTP had been in operation for over a one-year prior to the PACT process startup. The preliminary hydraulic testing revealed the following problems: 1) flooding of the primary clarifier weirs at about 18,000 gpm with one primary clarifier out of service, 2) an air entrainment problem between the RAS pump discharge and the RAS flowsplitter, 3) foaming in the mixed liquor and secondary effluent piping resulting in vent discharges, 4) excessive turbulence in the clarifier flowsplitter and clarifier flocculator area, 5) RAS flow restrictions, and 6) potential air binding with top takeoffs for WAS and secondary effluent recycle water. Mechanical modifications were made to correct or reduce each problem to a manageable level.

The goal schedule for the start-up after seeding is shown in Table 7 along with the actual timing achieved. It was originally planned that seeding would be done during warm weather, when biological activity would be greatest, but construction delays dictated a cold weather start-up. Because of the magnitude of the start-up effort, the proposed procedure was piloted in a temperature controlled laboratory unit. The tests showed there were no problems with cold start-up of a PACT system using actual primary effluent. Operating data plots are in the Appendix.

Prior to start-up there was considerable discussion about using an artifical feed of sodium acetate to assure the optimum environment for bacterial growth. This was not done because of the favorable laboratory results, and the large amount of organic that would have been needed. During the first 11 days of start-up over 5,200 kg/day of BOD was fed to the aerator. This increased to over 7,000 kg/day for the next 21 days. The cost of supplyiing this via purchased sodium acetate would have been substantial.

The general start-up procedure called for an initial charge of 60,000 kg (4,000 mg/liter) of powdered activated carbon to one of the 15,000 m^3 (4,000,000 gal.) aerators. The aerator would then be seeded with 2,000 mg/liter of biological solids.

Concurrently primary effluent would be fed through the aerator and one clarifier at one-half normal the operating rate. Wastewater flow would then be gradually increased to full rate. All this time a dose of 80 mg/liter of virgin activated carbon would be added to the feed. When the first aerator was at full rate and the biological system fully established, one-half the aerator MLSS were to be transferred to the second aerator. Flow to both aerators would be set at one-half normal rates and then gradually increased to full rate. The same procedure would then be used to start the third aerator.

TABLE 7. PACT LIQUID TRAIN START-UP, ACTUAL TIMING VS. GOAL SCHEDULE

Step	Actual Date	Goal Schedule
Training of 27 operators and 5 foremen complete	Nov., 1976	Nov., 1976
Hydraulic testing of aerators and clarifiers complete	"	"
Test carbon handling system	"	"
Test polymer, fuel oil, phosphoric acid, and HCL systems	"	"
Load 4000 ppm carbon to 1st aerator/clarifier	11/11/76	11/11/76
Start biological seeding 1st aerator	11/19/76	11/22/76
Start wastewater feed at low rate and 80 ppm carbon dose to 1st aerator	11/19/76	11/11/76
1st Aerator seeding complete	12/15/76	12/1 to 12/6/76
1st Aerator at full flow rate	01/08/77	12/20/76
Split MLSS between 1st and 2nd aerator	01/09/77	12/21/76
1st and 2nd Aerators at full flow rate	01/09/77	01/10/77
Split MLSS to 3rd aerator	01/31/77	01/10/77
All aerators on line at full rates and sludge fully acclimated.	02/12/77	01/24/77
Light off regeneration furnace, start two-week heat-up to operating temperature	02/16/77	12/06/76
Start filter press and regeneration furnace operation with PACT sludge	03/12/77	Jan.,1977

Two major deviations from plans occurred and extended the liquid train start-up phase by approximately one month from late January to late February.

A 1 mg/liter polymer dose to the clarifier, was proposed for normal operation. This was increased to 2 mg/liter during start-up to minimize the chance of MLSS being lost from the system by overflowing the clarifier. The polymer was recycled back to the aerator in the clarifier underflow. However, because of low biological activity during the initial seeding period, the polymer was not biologically degraded as it normally would be, and it began to concentrate. The result was that all the MLSS (activated carbon and biological seed) combined with the polymer and settled to the bottom of the aerator as the mixers were unable to keep the MLSS suspended. Once the cause of the problem was realized and polymer addition stopped, the solids were easily re-suspended and the start-up proceeded normally. The problem of original concern, MLSS loss from the clarifier, never was significant, even at the relatively low water temperature, 10°C minimum, experienced with this winter start-up.

Later during start-up, in January, 1977, a sludge rake on the bottom of one of the clarifiers failed. The rake's function was to move settled solids to the bottom center of the clarifier where the 0.61 m diameter underflow line to the recycle sludge pumps exits. The broken rake permitted solids to accumulate on the bottom of the clarifier. Until this accumulation was discovered, and the broken rake repaired, there was no increase in aerator MLSS concentration. Once these solids were returned to the aerators MLSS, concentration increased rapidly. Wastewater feed and carbon dose were then restricted to minimize MLSS build-up until the solids train (sludge thickener, filter press, and carbon regeneration furnace) was ready to operate and permit wasting of solids.

During the seeding period, which, with an interruption over Thanksgiving week extended from November 19, 1976 to December 15, 1976, a total of 42,000 kg dry weight of biological solids were trucked to Chambers Works and pumped into the aerator. Biological solids were obtained from two New Jersey waste treatment plants. Most came from the Gloucester Regional Treatment Plant; the remainder came from American Cyanamid's Bound Brook plant.

Aerator temperature during this time varied from 10 to 21°C. Foaming in the aerators, which had been a problem during hydraulic testing when the wastewater was aerated, stopped as soon as the powdered carbon was added to the aerators.

Aerator ATP concentration was monitored during the seeding period and appeared to mirror the growth of active bacterial mass (Ref. 6).

The liquid train was capable of full flow operation in February. However, there were delays in start-up of the solids train, and so the plant was limited in the amount of solids which could be wasted. To minimize the build up of solids in the liquid train, flow to the PACT process was restricted until June, 1977. Full flow had to be accepted then to meet a NPDES permit deadline for full wastewater treatment.

Start-up of the solids train commenced in January, 1977. It took over thirteen months, until February, 1978, before all portions were running satisfactorily. A monthly chronology of the solids train start-up follows:

1977 - January

PACT filter press was tested with water and ready to receive sludge. The regeneration furnace had been run cold with air and water, and the acid washing system had been tested with water. Many mechanical problems with the filter required attention.

1977 - February

Regeneration furnace burners were lit and brick was being dried by low level heating. During the wait for furnace start-up, improvements were made in the hydraulic system for the press.

1977 - March

PACT sludge filtration started at mid-month. Press hydraulics worked well; there were mechanical problems. Cake solids were at 40% vs. 38% goal, but cycles were longer, 90 minutes vs. 75 minutes. Furnace was up to operating temperature and enough sludge was fed to displace dead bed and allow collection of some activated carbon, which was sent to storage. Sludge feed to the furnace was sporadic because of mechanical problems with the press, conveyors, and furnace discharge chute to the quench tank.

1977- April

Furnace made regenerated carbon with good activity. Then # 3 hearth dropped and damaged # 4 hearth so both needed replacing. Furnace was cooled down and damaged brick removed. CY-282 "Z" conveyor had 20 torn flites, and was down two weeks. A decision was made to store PACT sludge in the primary landfill while the furnace was down.

1977 - May

PACT filter press and conveyor ran consistently, but at only 1/3 design rate. It was decided to upgrade quality of furnace brick. Almost all old brick was removed during month. Mathematical models indicated skewband overheating could have contributed to hearth failure.

1977 - June

Acid washing of filter press seems to have halted deterioration in performance (this success was not repeated). A slower, fluid type drive was installed on the "Z" conveyor. Extensive laboratory testing relieved concern that new furnace brick did not meet specifications. Hearths # 2, 3, and 4 were re-built.

1977 - July

Furnace re-bricking was completed. A parallel weigh belt conveyor (CY-301B) and gatelock feeder, plus two new feed screws to weigh belts were installed. The "Z" conveyor was shortened approximately 4.6 meters to reduce wear. A Mechanical engineer was assigned full time to filter press, filter press feed pumps, and conveyor problems. Press plus conveyor in time was only 46%; while the press was operating it ran at an 11.2 cycles/day rate. The main cause of press downtime was filter cloth holes.

1977 - August

All re-construction and instrumentation was completed by start of month. Start-up was delayed for special operator training and a thorough safety review. Water and air flows were on furnace by month end. Filter press and conveyor in time was 58%; while the press operated it ran at an 8.8 cycles/day rate. Four types of metal cloths and two different cloth support materials were tested.

1977 - September

After some burner repairs the furnace was re-heated and sludge feed was started 9/24. Furnace went down one day later because a rabble arm tooth was rubbing on a hearth (hearths rise significantly as they are heated). Press and conveyor in time was 65%; main cause for downtime was "Z" conveyor failures rather than holes in filter cloths. While operating, the press ran at 8.0 cycles/day rate.

1977 - October

Furnace was cooled so the teeth on several rabble arms could be shortened. The furnace brick was found in excellent condition. The furnace was re-heated and operated 10 days at 52% feed in time. Feed outages were caused by "Z" conveyor shutdowns. The furnace was put in hot stand-by condition for assessment of possible hearth damage from erratic feed and consequent temperature control problems. Press filtration cycles were beginning to lenthen. The addition of cellulosic admix at a ratio of 7 kg. admix/100 kg. PACT solids aided filtration, but this was impractical for routine operation because of lack of facilities.

1977 - November

It was decided that temperature excursions were not harming the hearths, and furnace feed resumed. The furnace ran at 73% in time with feed conveyor problems responsible for most of the downtime. At month end a drop chute fell, and the tool furnished for hot removal of chutes from the furnace did not work. The furnace was cooled down and held down for a scheduled re-building of CY-282 "Z" conveyor into a much heavier "L" conveyor; and for installation of 24.4 meter screw conveyor CY-293. PACT press in time was 61%; the downtime was caused by cloth holes plus conveyor problems. The press ran at a 5.2 cycles/day rate while running. Some filter cycles took up to 4 hours.

1977 - December

The furnace drop chute supports were changed to stronger, more heat-resistant materials of construction. All the new conveyor work was completed. A bigger drive was installed on bunker conveyor CY-281. The furnace was held down until the new conveyors could be thoroughly checked out. PACT press in time was only 42% because of cloth changes and conveyor construction interferences.

1978 - January

The tool to remove chutes from the furnace while it was hot was modified and proven out in a cold test. The furnace was heated to temperature and sludge feed was started 1/28. PACT press production was a record 8.7 cycles/day including a downtime of only 10%. The improved press performance was believed related to the higher carbon dose to the aerators and the resultant lower bio-mass/activated carbon ratio in the sludge.

1978 - February

The solids train was down one week for a fractured drive sprocket on bunker conveyor CY-281. Excluding this, furnace feed in time was 84% with feed rate at 57% of design. Regenerated carbon quality was up to two thirds of goal by month end. The press ran at a total rate of 6.6 cycles/day including all downtime. A fan was installed to vent the weigh belt conveyors and eliminate a fume problem at top of furnace.

Summary of Startup

The liquid train start-up was excellent. Solids train start-up dragged because of under-designed equipment and the furnace hearth failure. Major improvements were made to the solids train and it was operating consistently, but at less than design rates, by February 1978. The principal of powdered carbon regeneration in a full size multiple hearth furnace had been demonstrated.

Detailed, average operating data for the start-up are presented in Table A-2.

OPERATING COSTS

It cost approximately $16,500,000/year to operate the Chambers Works wastewater treatment plant in 1978 and 1979. Of this, approximately $10,000,000, or 65% is the estimated cost of PACT secondary/tertiary treatment. Primary treatment costs include over $1,500,000 to purchase the lime needed for acid neutralization. Annual depreciation charges of $4,000,000 on a book investment of over $45,000,000 make up 25% of the annual operating costs.

Average annual operating costs for 1978 and 1979 are shown in Table 8. As this study deals with PACT treatment only, in developing Table 8 each individual item of cost has been proportioned as accurately as possible between primary and secondary/tertiary treatment.

At the average plant flow of 94 m^3/min. (24,900 gpm) costs have averaged \$.33/m^3, (\$1.27/1000 gal.) for total treatment or \$0.22/m^3 (\$0.82/1000 gal.) for PACT treatment only. Because many costs are independent of load, unit costs would drop significantly if the plant were operated closer to capacity. Many treatment facilities report costs exclusive of depreciation charges. Ignoring depreciation, the cost for PACT treatment has averaged \$0.16/m^3 (\$.61/M gallon).

TABLE 8. WASTEWATER TREATMENT PLANT OPERATING COSTS

	Average Annual Costs[1] In Thousands		
Cost Items	Primary Treatment	PACT Secondary/ Tertiary Treatment	Total
Lime	$ 1,540	$ -	$ 1,540
Other Raw Materials-Primary	150	-	150
Activated Carbon	-	3,010	3,010
Polymer, PACT	-	190	190
Filter Aid, PACT	-	20	20
Acid for Carbon Washing-PACT	-	20	20
Phosphoric Acid-PACT	-	30	30
Total Raw Materials	$ 1,690	$ 3,270	$ 4,960
Primary Treatment-Utilities	460	-	460
PACT-Steam	-	70	70
PACT-Fuel Oil	-	170	170
PACT-Electricity	-	610	610
PACT-Other Utilities	-	20	20
Total Utilities	460	870	1,330
Operating Labor	420	420	840
Mechanical Labor, Materials	560	1,670	2,230
Salary Personnel	230	380	610
Depreciation	1,430	2,650	4,080
Overheads	340	770	1,110
Computer	50	60	110
Miscellaneous Supplies	-	270	270
Laboratory Support	-	160	160
Other Services	-	150	150
Other Primary Treatment Expenses[2]	670	-	670
Total Other Costs	3,700	6,530	10,230
Total Plant Costs	$ 5,850	$ 10,670	$16,520

1 Average for Years 1978 and 1979

2 Including Landfill Charges

In attempting to extrapolate these costs to other waste treatment operations, it must be realized that operating and mechanical personnel involved with the Chambers Works plant are relatively well paid. Their average earnings approach $10/hour plus an additional 40% for fringe benefits. A rough estimate of the current replacement value for the total treatment plant is $60,000,000; the PACT process share of this updated investment is about 65%. Direct maintenance costs, including all overheads, have run about 3.7% of total updated investment. Maintenance costs are forecast to decrease significantly in 1980 as a result of mechanical improvements over the past two years.

The plant is currently staffed with 29 operators, four salaried shift supervisors, two day supervisors, plus six other management and technical people. There are approximately 30 mechanics, electricians, and instrument technicians currently assigned to the plant. Both operating and mechanical staffs are forecast to drop by 15 to 20% in the next year.

BIOLOGICAL MONITORING

During plant construction it was anticipated that some type of biological monitoring of effluent quality might be required by regulatory authorities. A bio-assay laboratory was included in the filter press and control room building. It was equipped with flow through aquaria which could be fed a controlled mix of river water and plant effluent. Mummichog minnows (*Fundulus Heroclitus*) had been specified by the Delaware River Basin Commission as an appropriate test species for the Delaware River estuary, and accordingly all tests have been made with these fish.

When the plant started up, no bio-assay test requirement was included in the Chambers Works NPDES permit. It should be noted that the permit applies to the discharge to the river, not the effluent from the treatment plant itself. As noted earlier, treatment plant effluent is diluted with 1.5 times its volume of non-contact cooling water before discharge to the river. Most of the water used on Chambers Works is drawn originally from the Delaware estuary.

Despite the absence of any regulatory requirements, it was decided to run bio-assays to see if the results would be useful in monitoring treatment plant performance. To use the bio-assay results in this way, it was necessary to find a mixture of river water and treatment plant effluent that would cause a significant number of fatalities of the test species under normal conditions. Then a change in the quality of the effluent could be expected to change the fish survival rate. After a series of preliminary batch tests, a mix of 75% treatment plant effluent/25% river water was selected.

TABLE 9. FLOW THROUGH BIO-MONITORING TEST RESULTS

Test Start	Number of Fatalities	Average PACT Effluent DOC During Test Period
06/05/78	3	26 mg/liter
05/31/78	10	38 "
05/15/78	2	30 "
05/08/78	10	39 "
04/10/78	2	34 "
04/04/78	7	34 "
03/27/78	3	39 "
03/15/78	1	48 "
03/03/78	0	33 "
02/21/78	0	41 "
02/14/78	3	30 "
02/09/78	10	50 "
02/01/78	5	33 "
01/05/78	0	32 "
12/07/77	6	35 "
11/29/77	1	40 "
11/21/77	4	35 "
11/15/77	0	27 "
11/09/77	5	28 "

Test mixture was 75% PACT effluent and 25% estuary water.

Tests were run for 96 hours and 10 fish were used in each test.

Starting in November, 1977, flow through, 96-hour tests were made at periodic intervals. Test results are shown in Table 9. In June, 1978 it was decided to discontinue these tests. A plot of fish survival rate vs. the DOC content in the effluent showed no correlation, although it was true that when effluent quality was very bad, there was 100% mortality. However the test was much too imprecise a measure of quality as compared to DOC analysis.

Throughout much of this period, weekly static bio-assay tests were also run. These were made with mixes of river water and Chambers Works effluent from main outfall 001, not treatment plant effluent. The results consistently showed the non-toxicity of the 001 discharge. There was no significant difference in survival rate in a 3/1 river water/effluent mix vs. 100% effluent.

In late 1978 the New Jersey Department of Environmental Protection requested monthly, flow through toxicity tests. After review of past results and some negotiation, it was agreed that the plant would test a 25% treatment plant effluent/75% river water mix once each month. For flow through testing it was more convenient to use treatment plant effluent rather than 001 effluent. If the survival rate was better than 50% in the mix tested, it would assure the more dilute 001 effluent was also within limits. Official testing began in April, 1979. Since that time all tests have shown survival rates over 50%.

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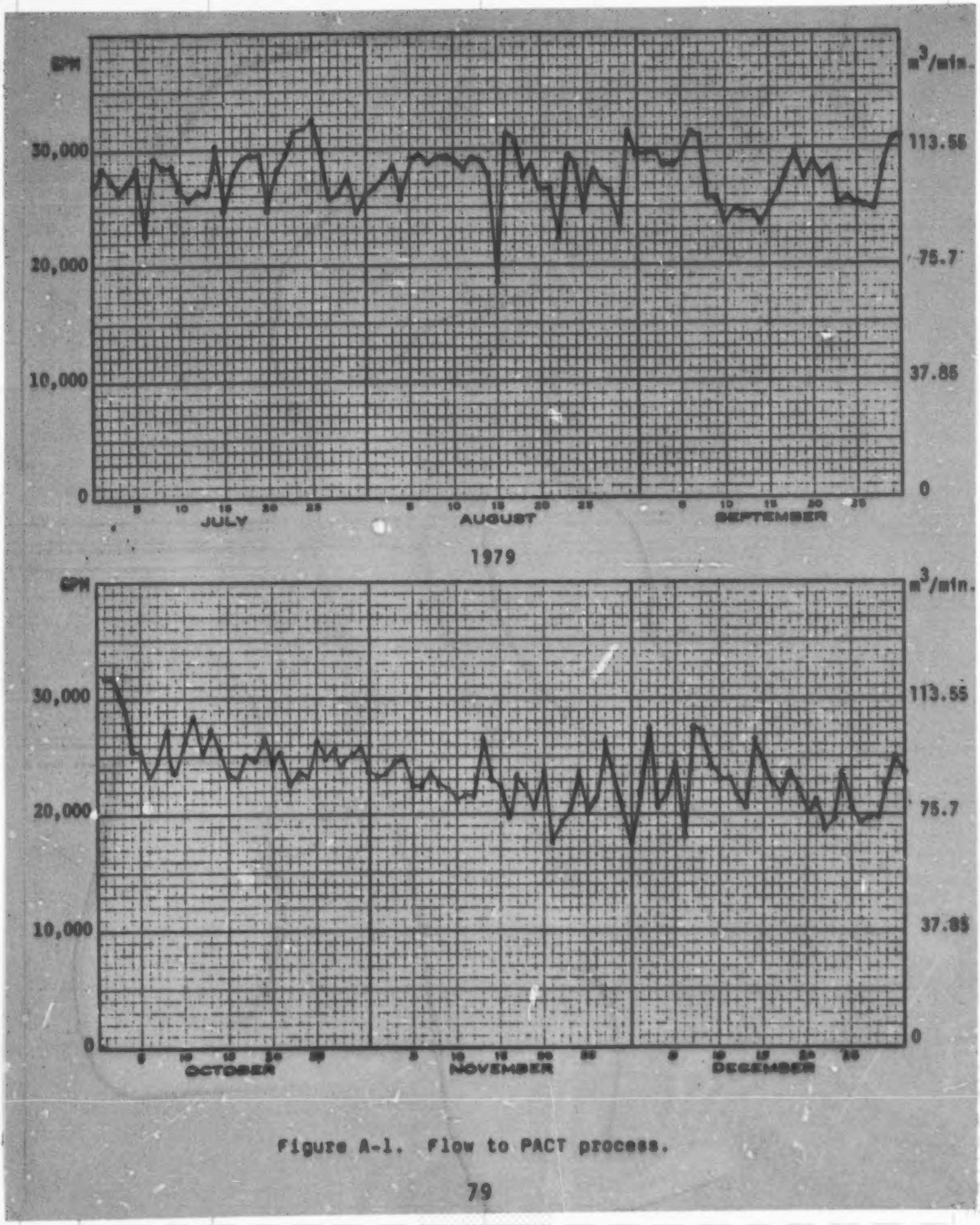

Figure A-1. Flow to PACT process.

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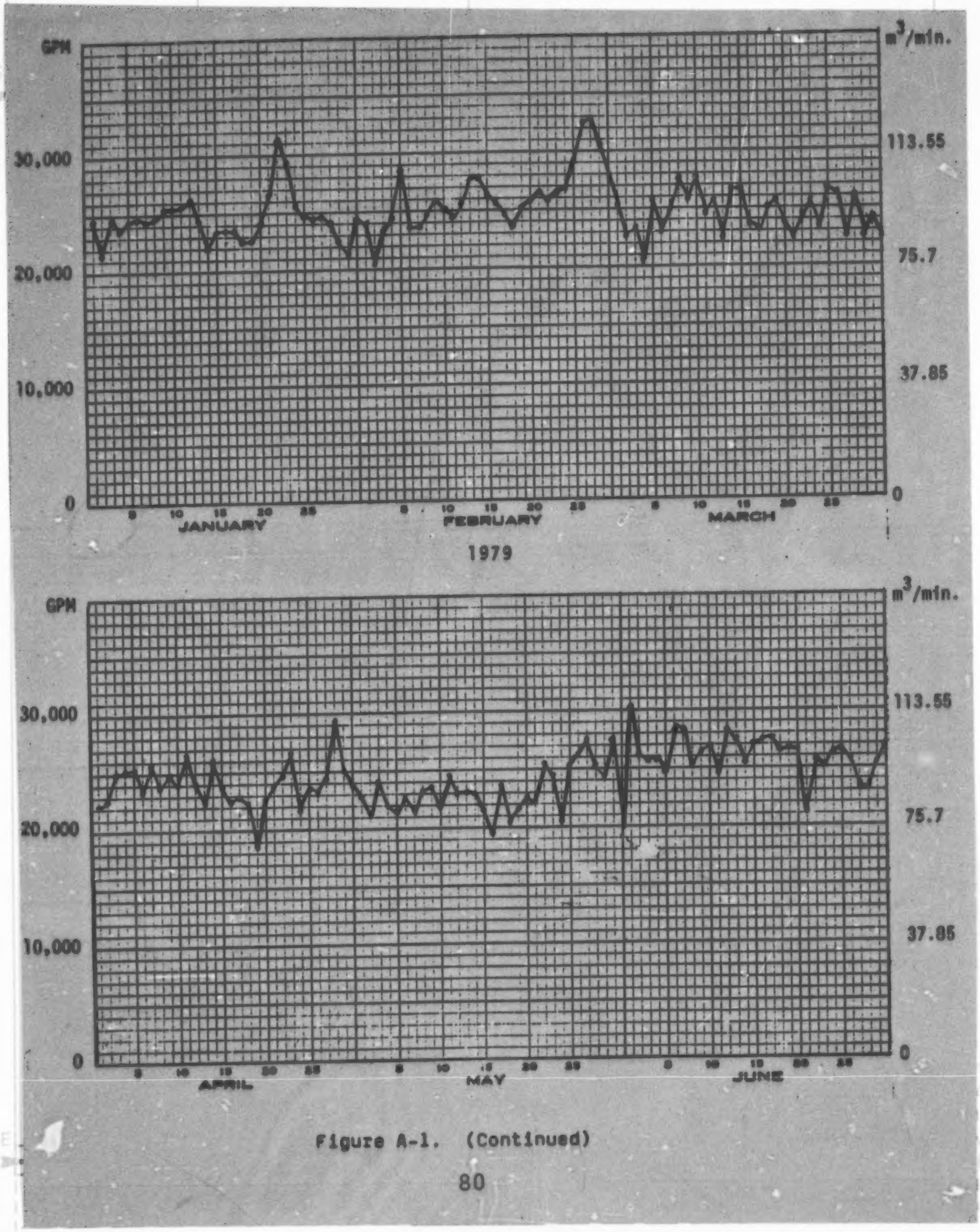

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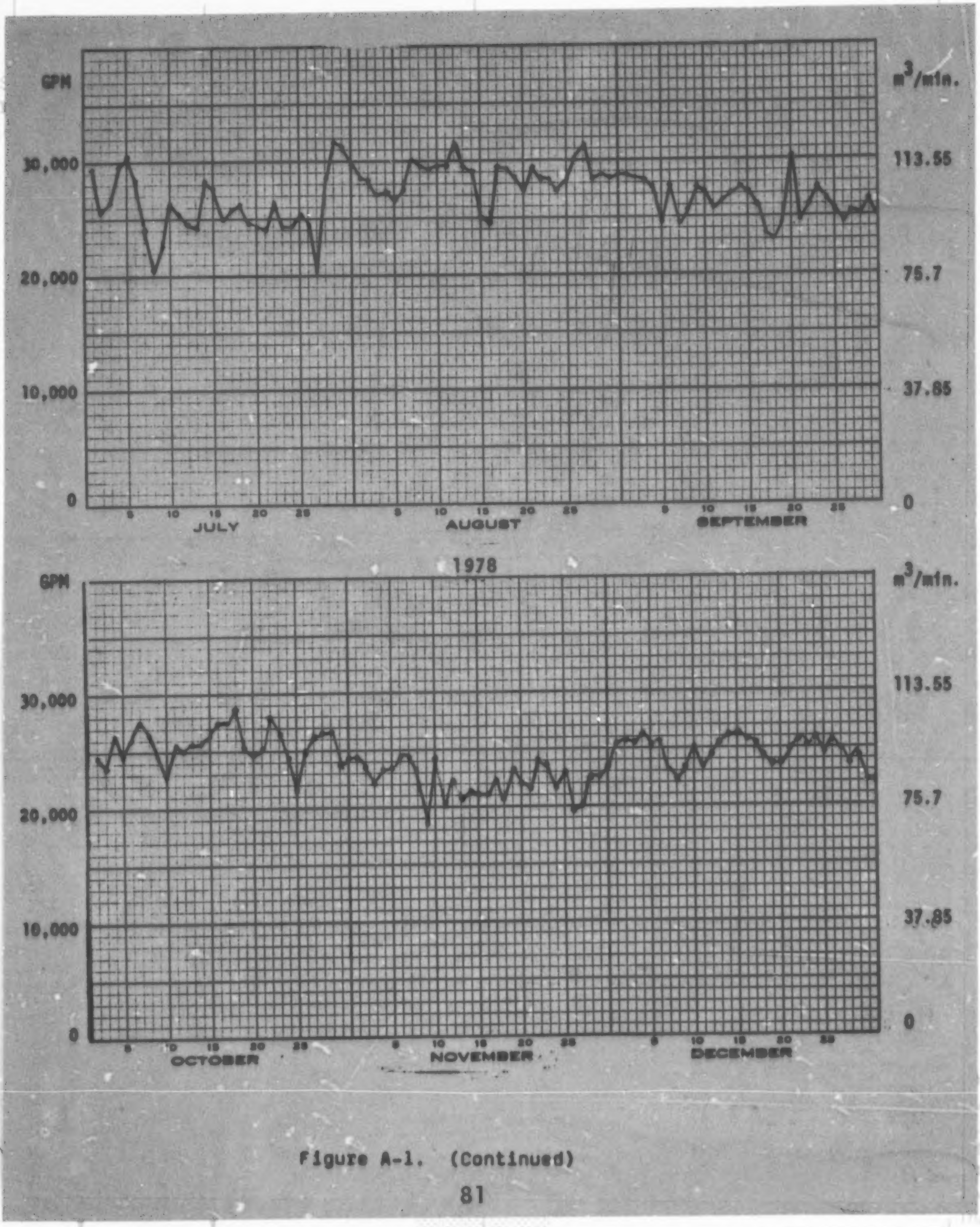

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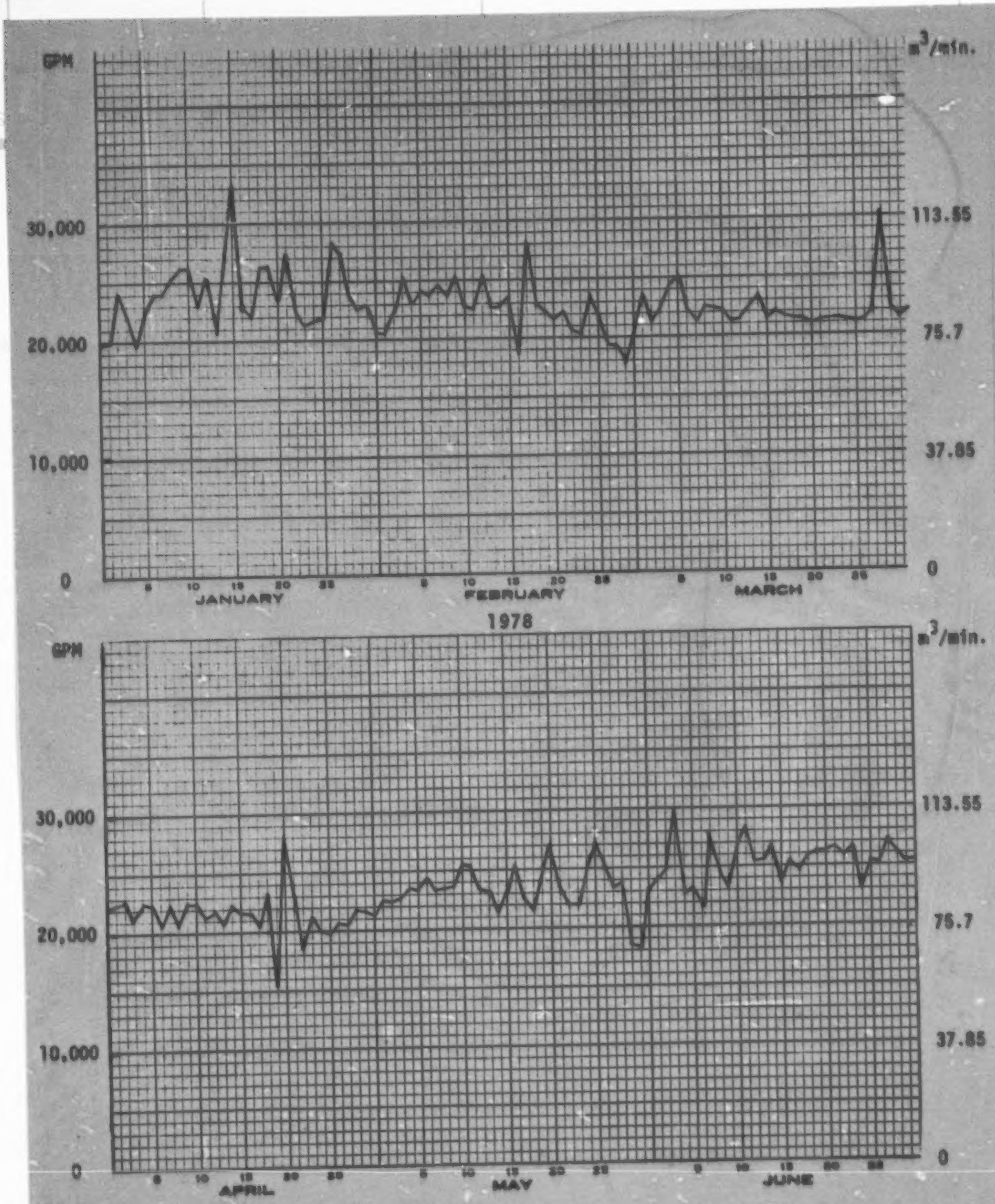

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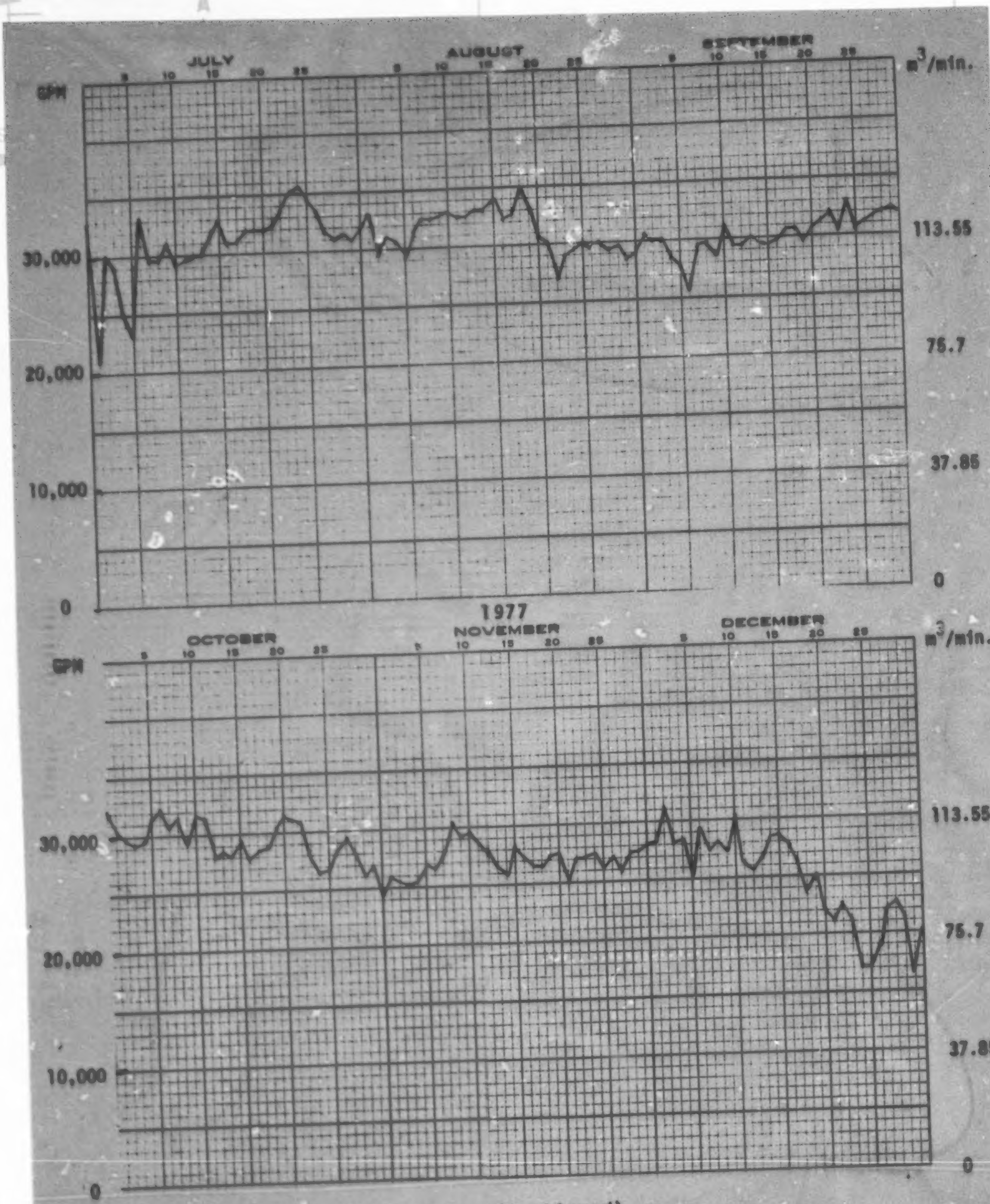

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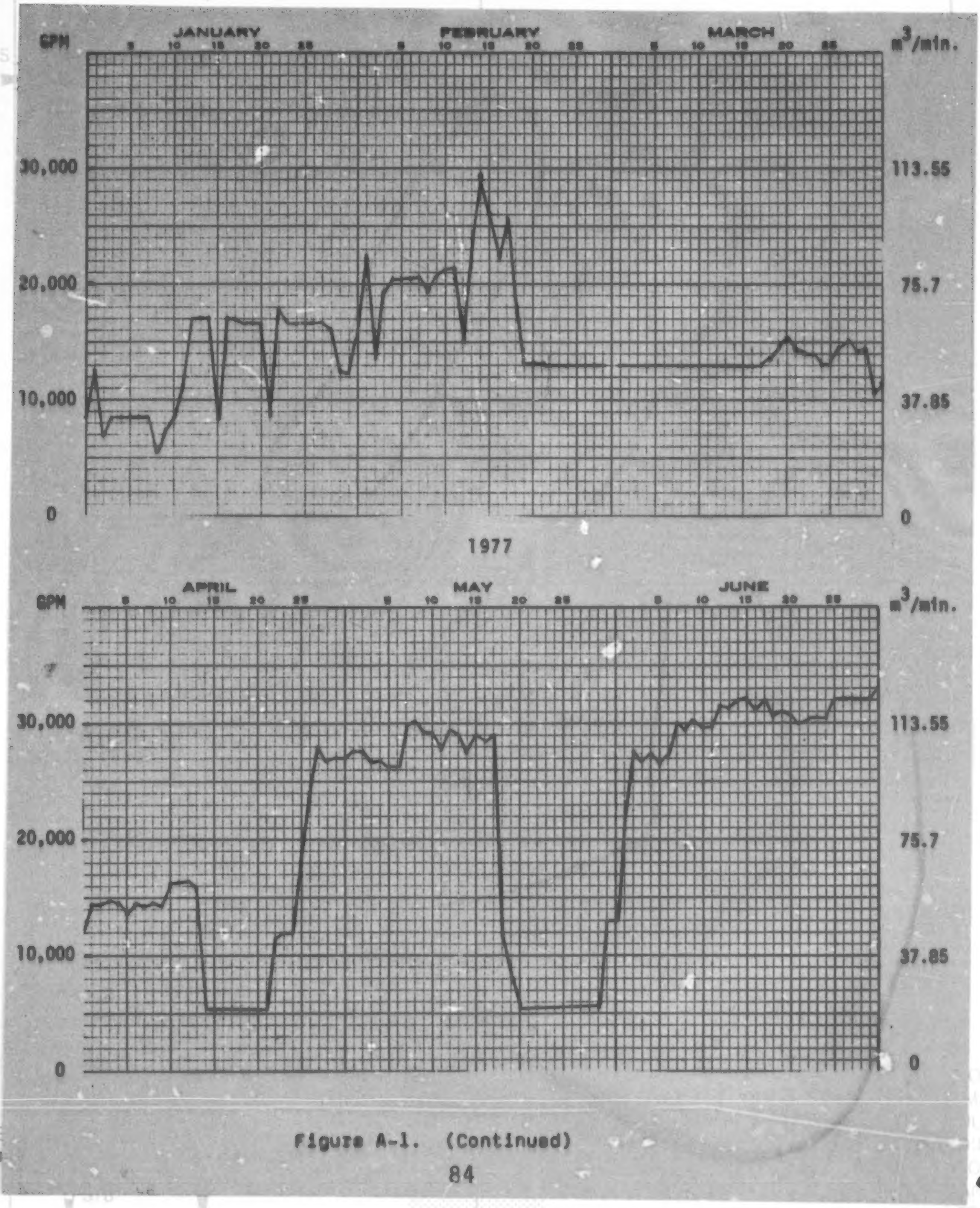

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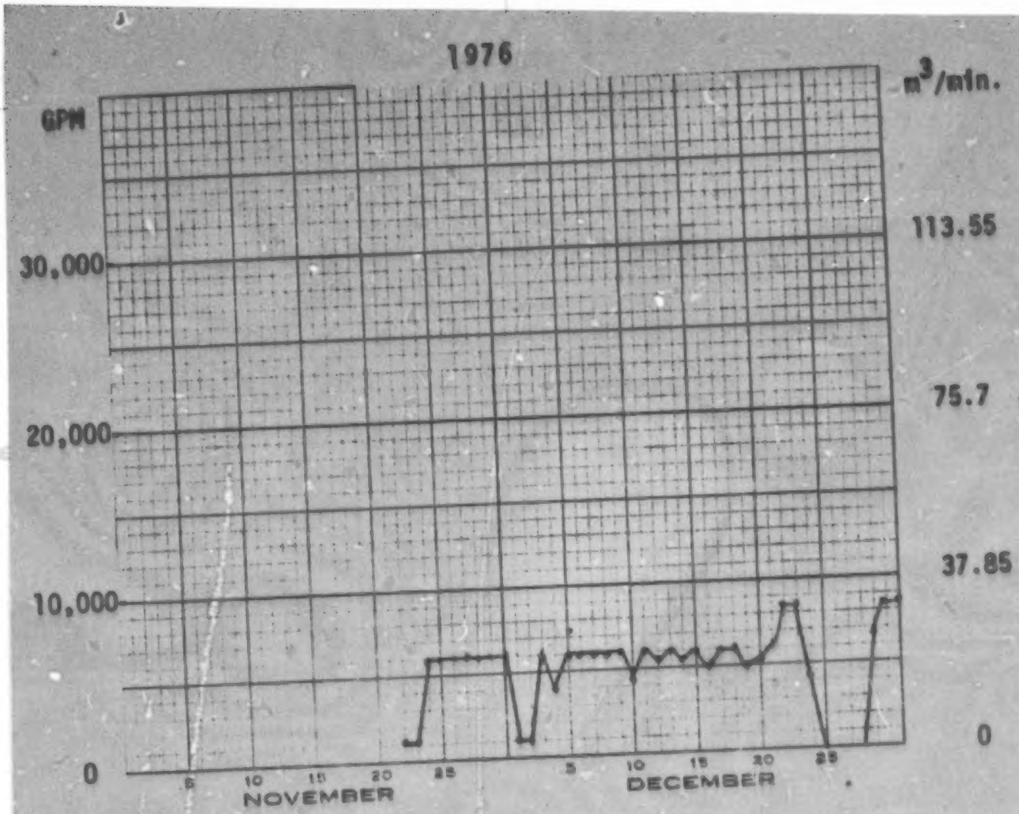

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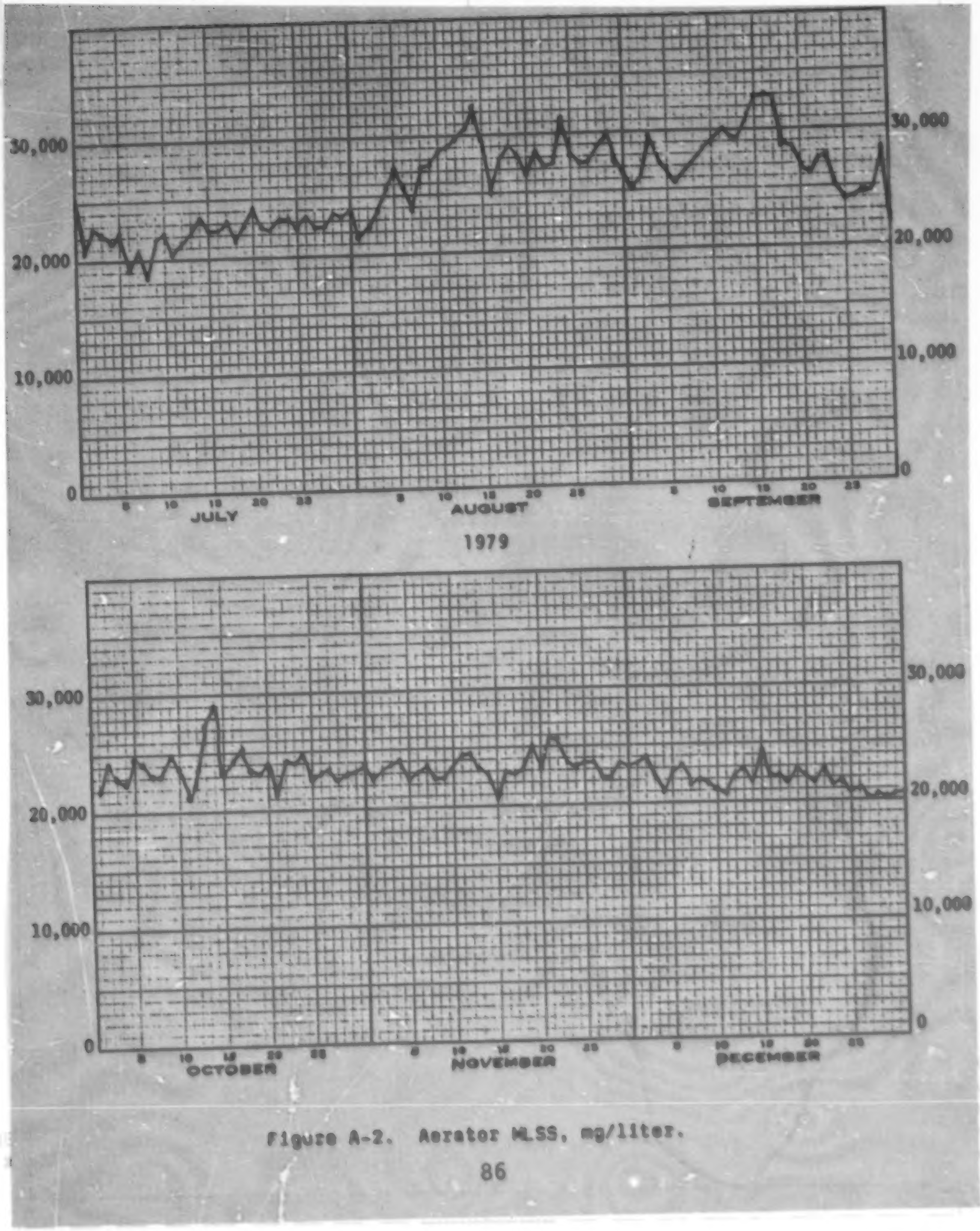

Figure A-2. Aerator MLSS, mg/liter.

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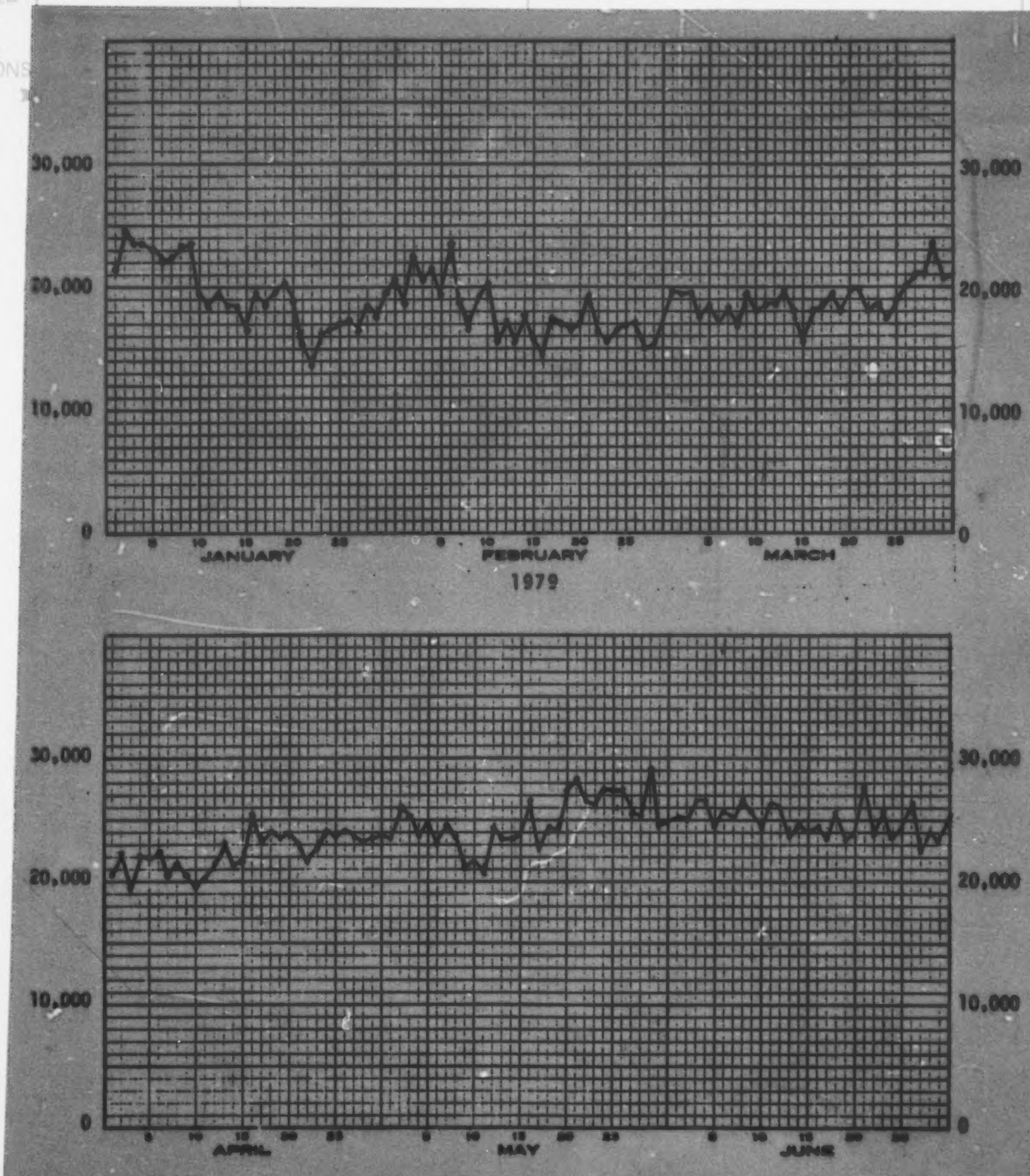

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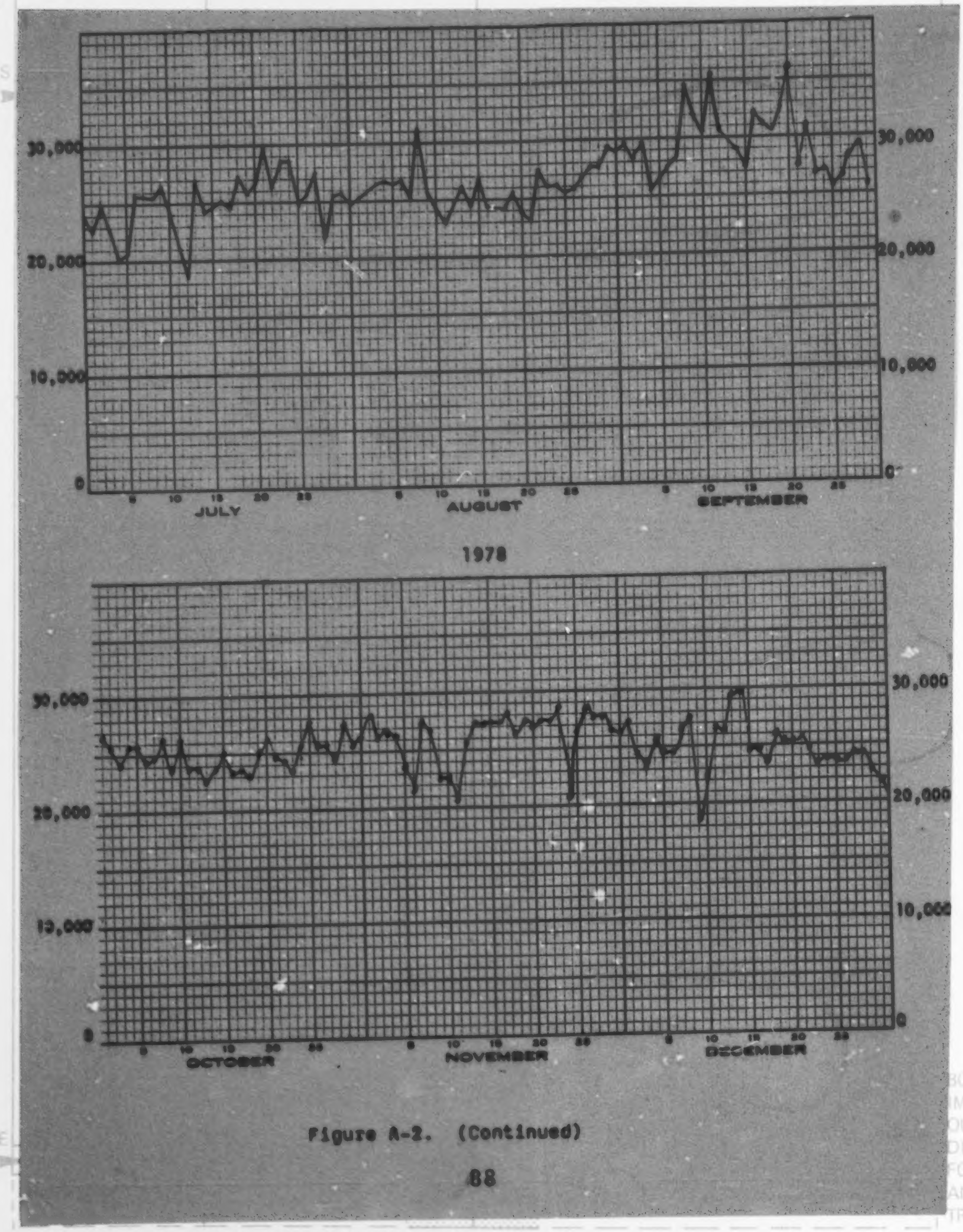

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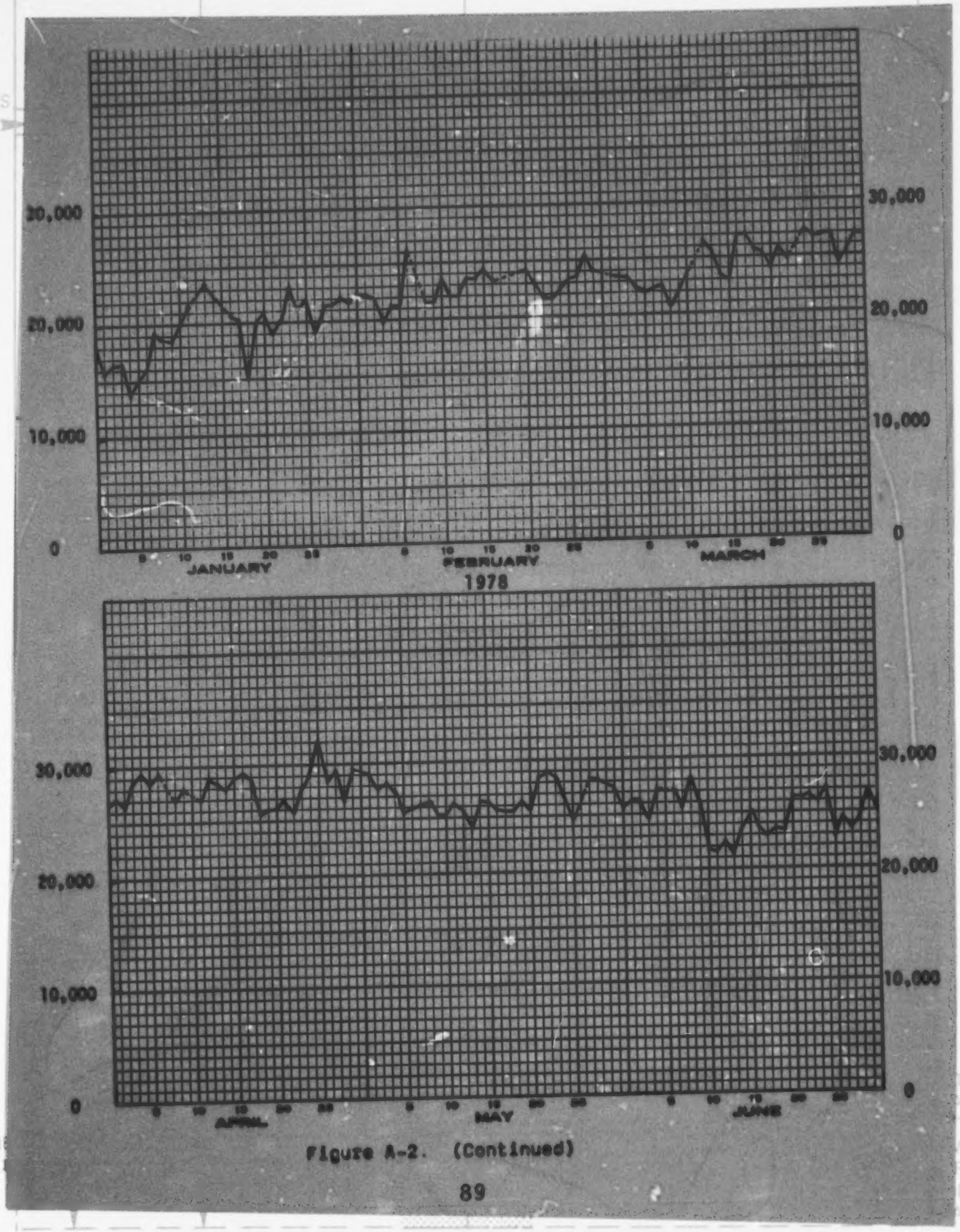

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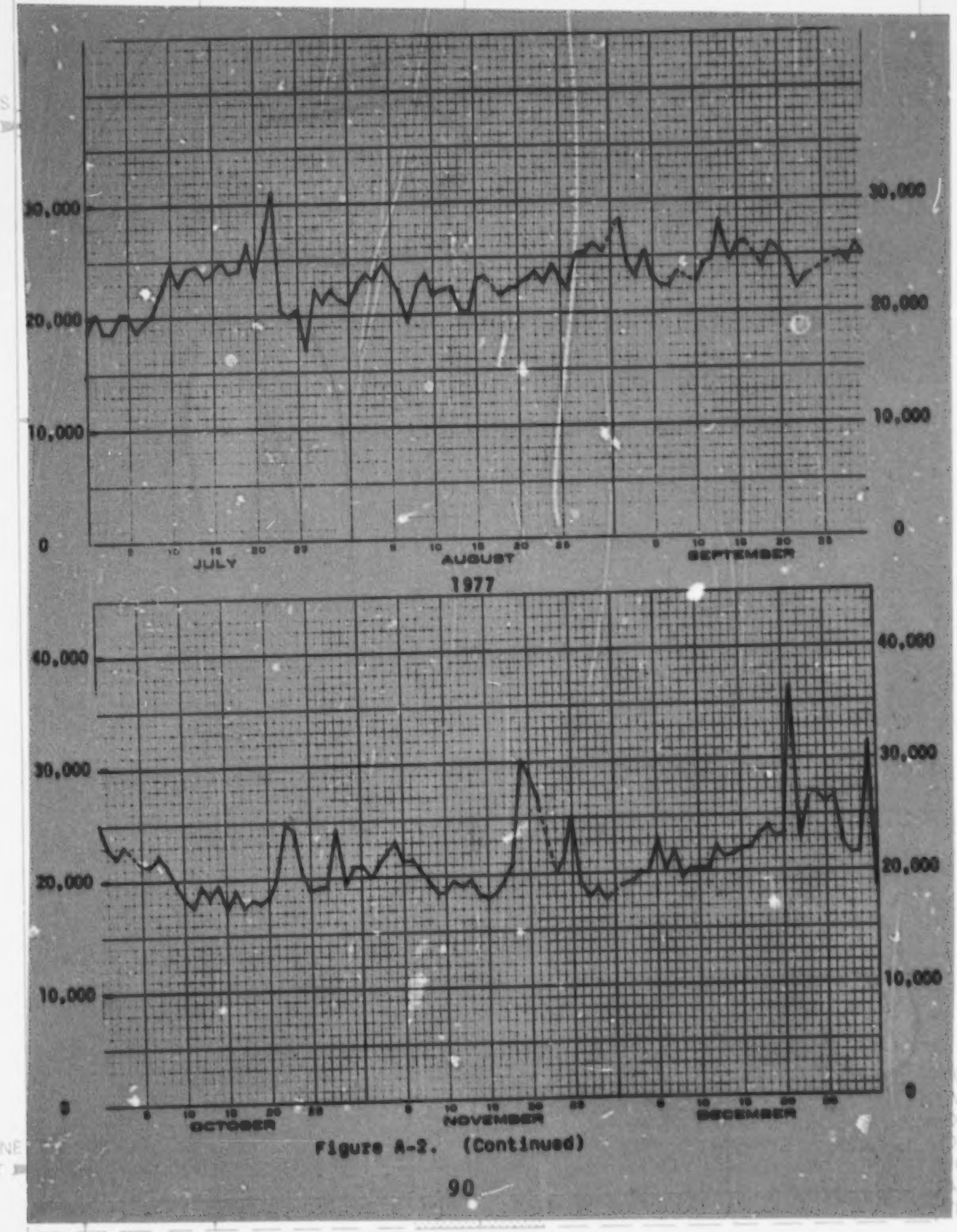

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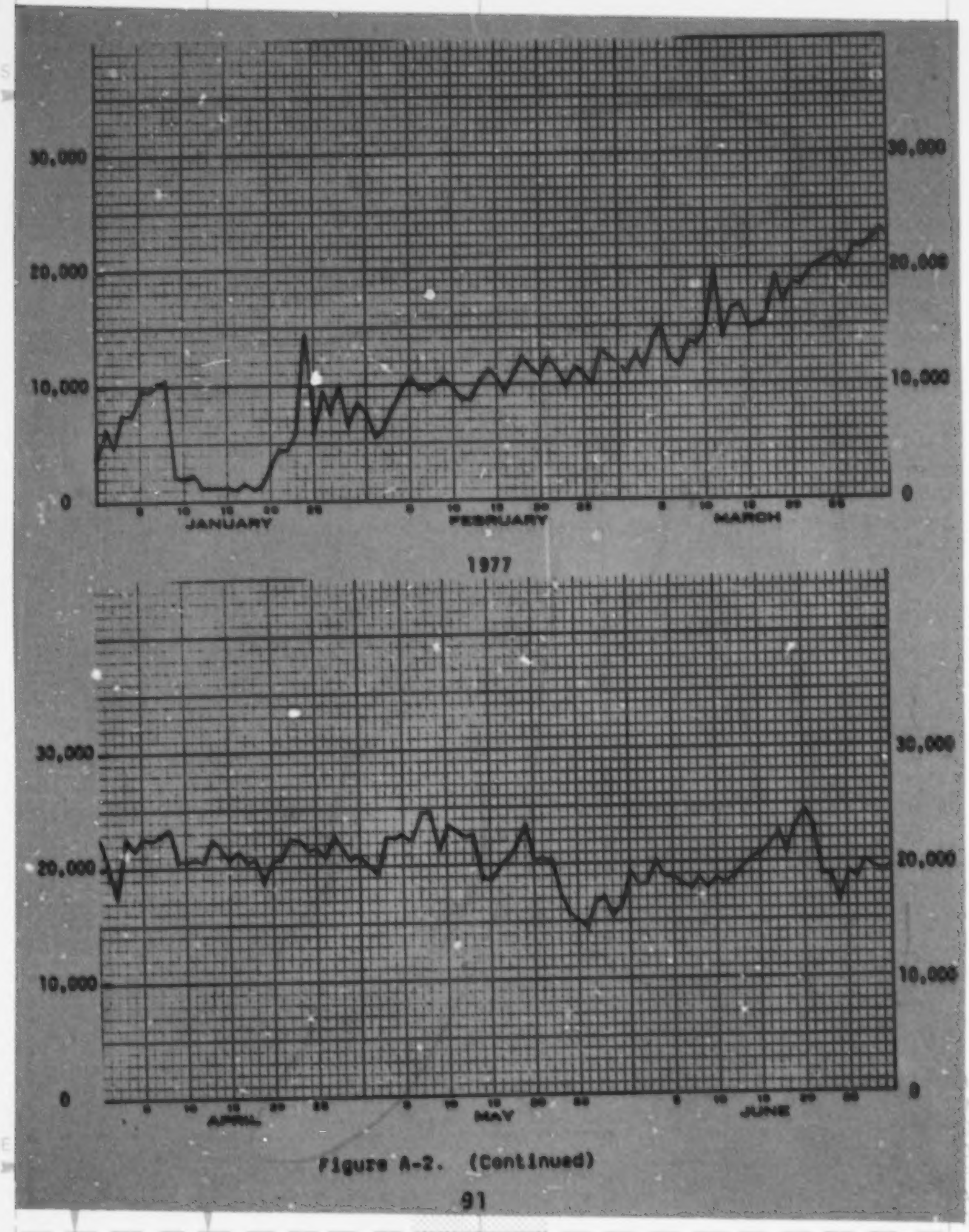

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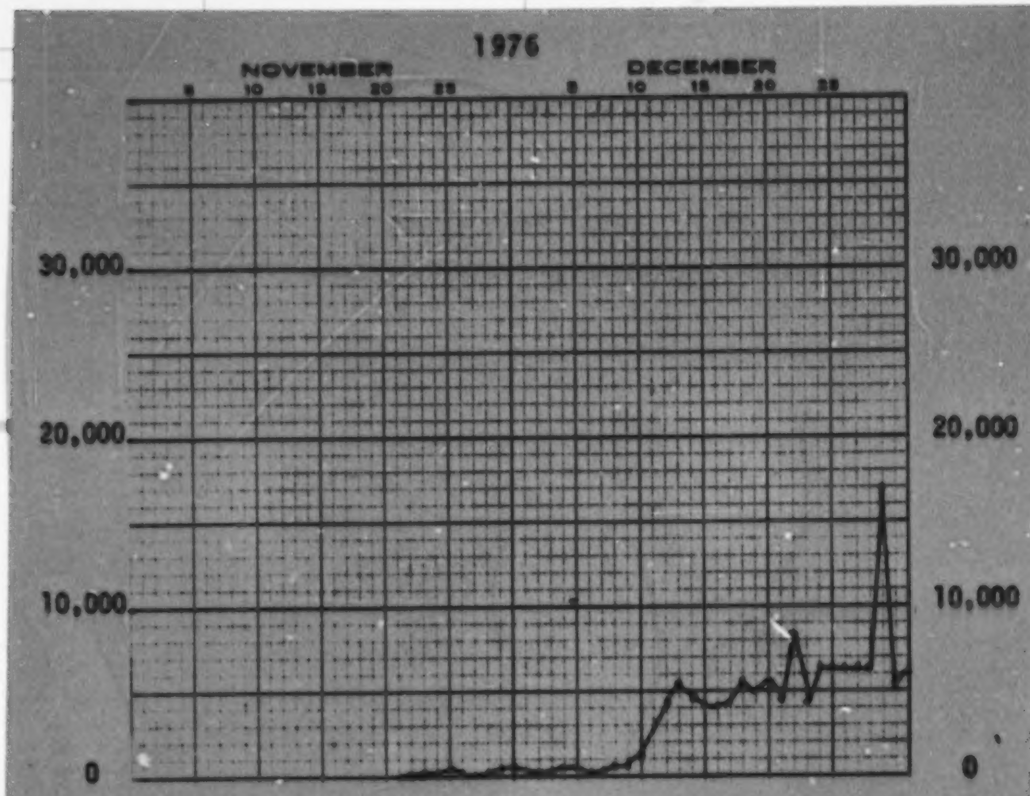

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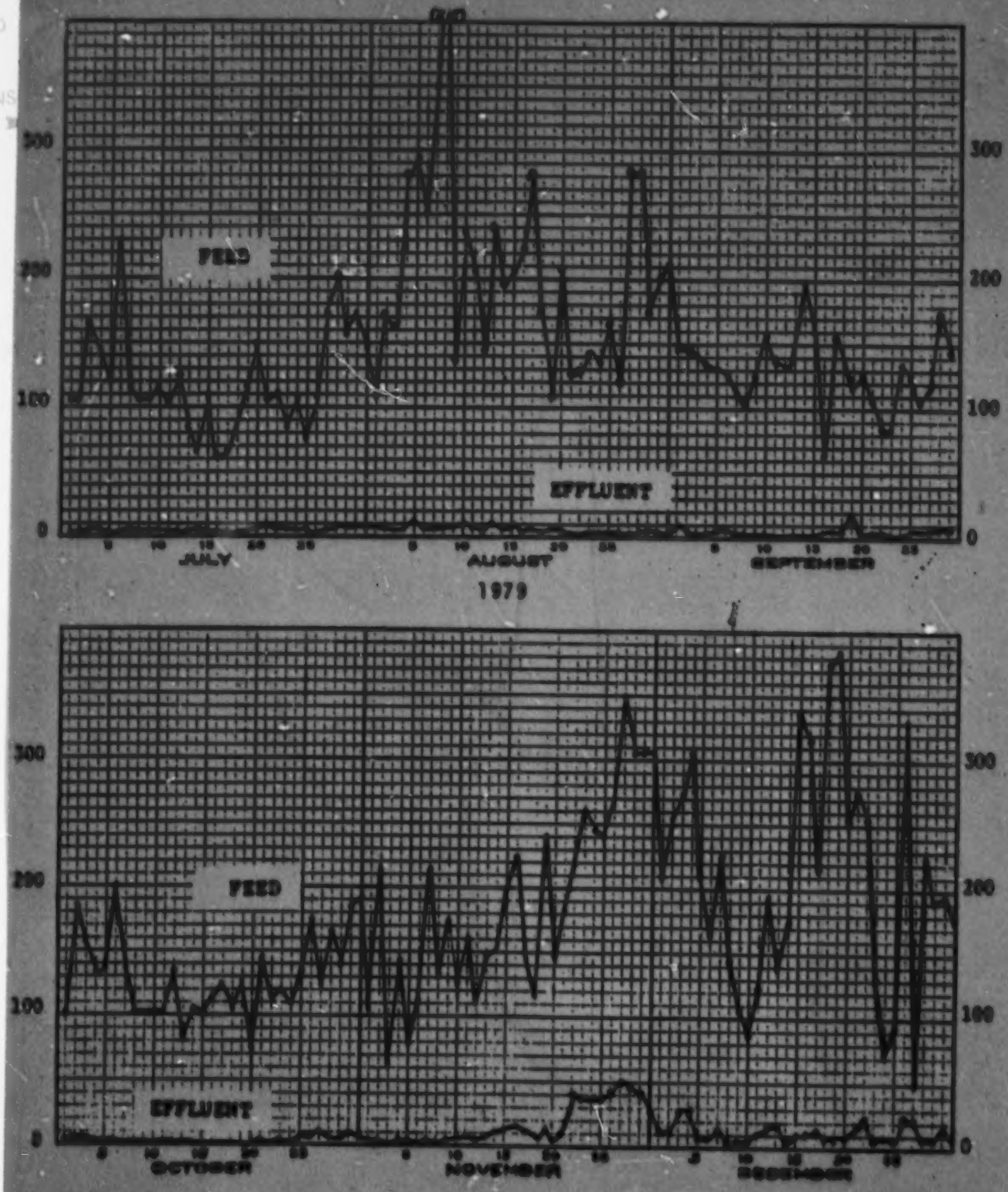

Figure A-3. PACT process feed and effluent soluble BOD_5 concentration, mg/liter.

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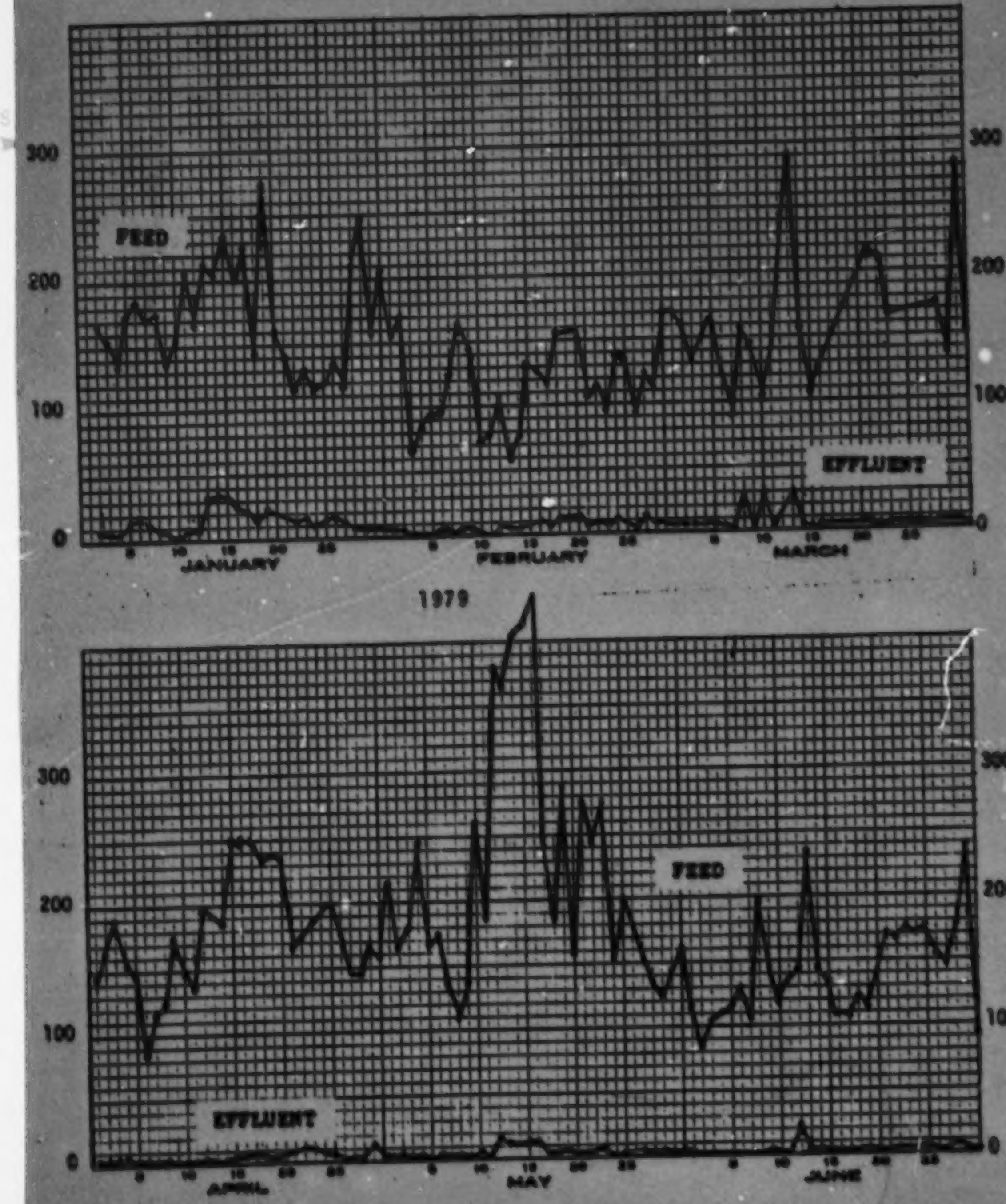

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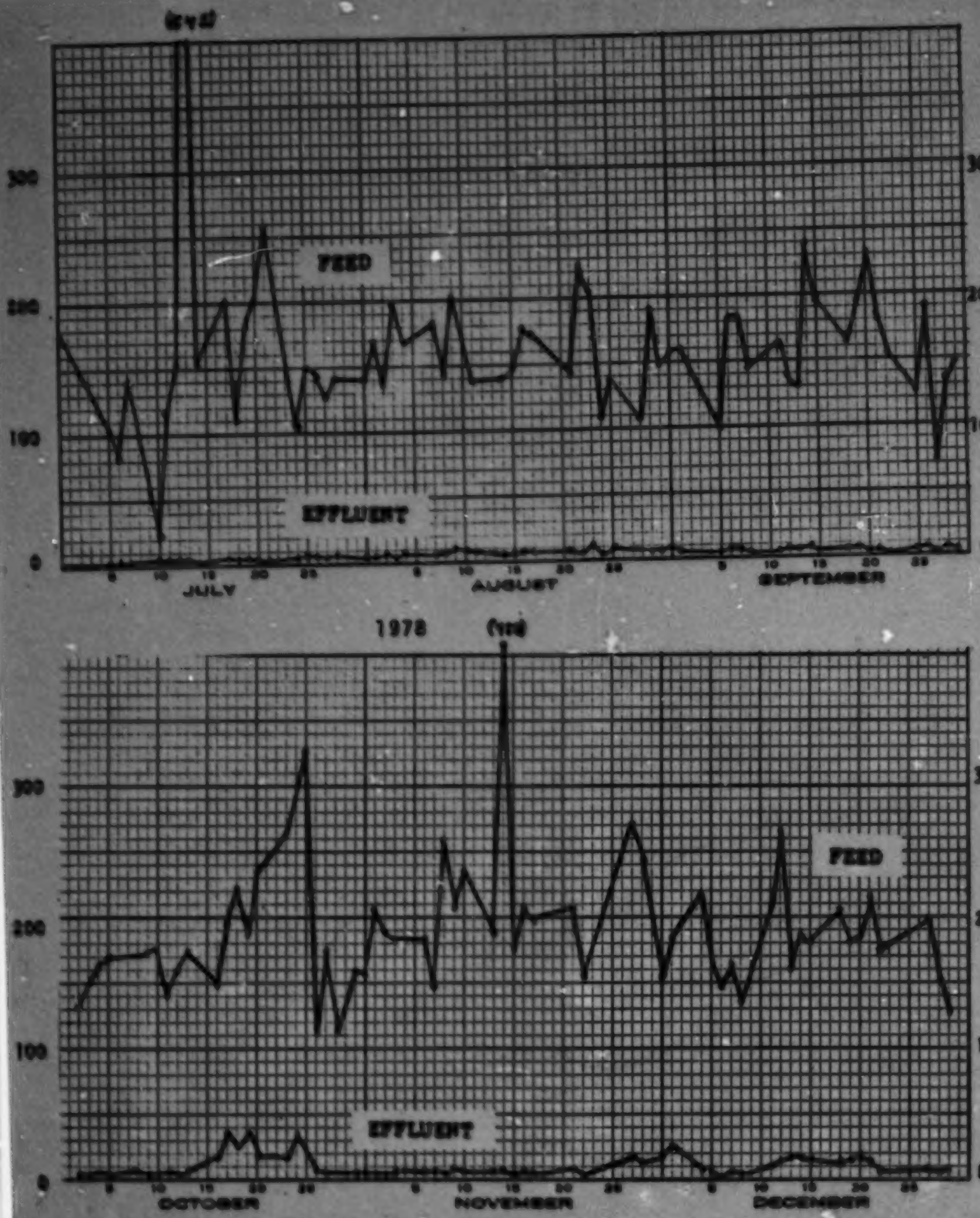

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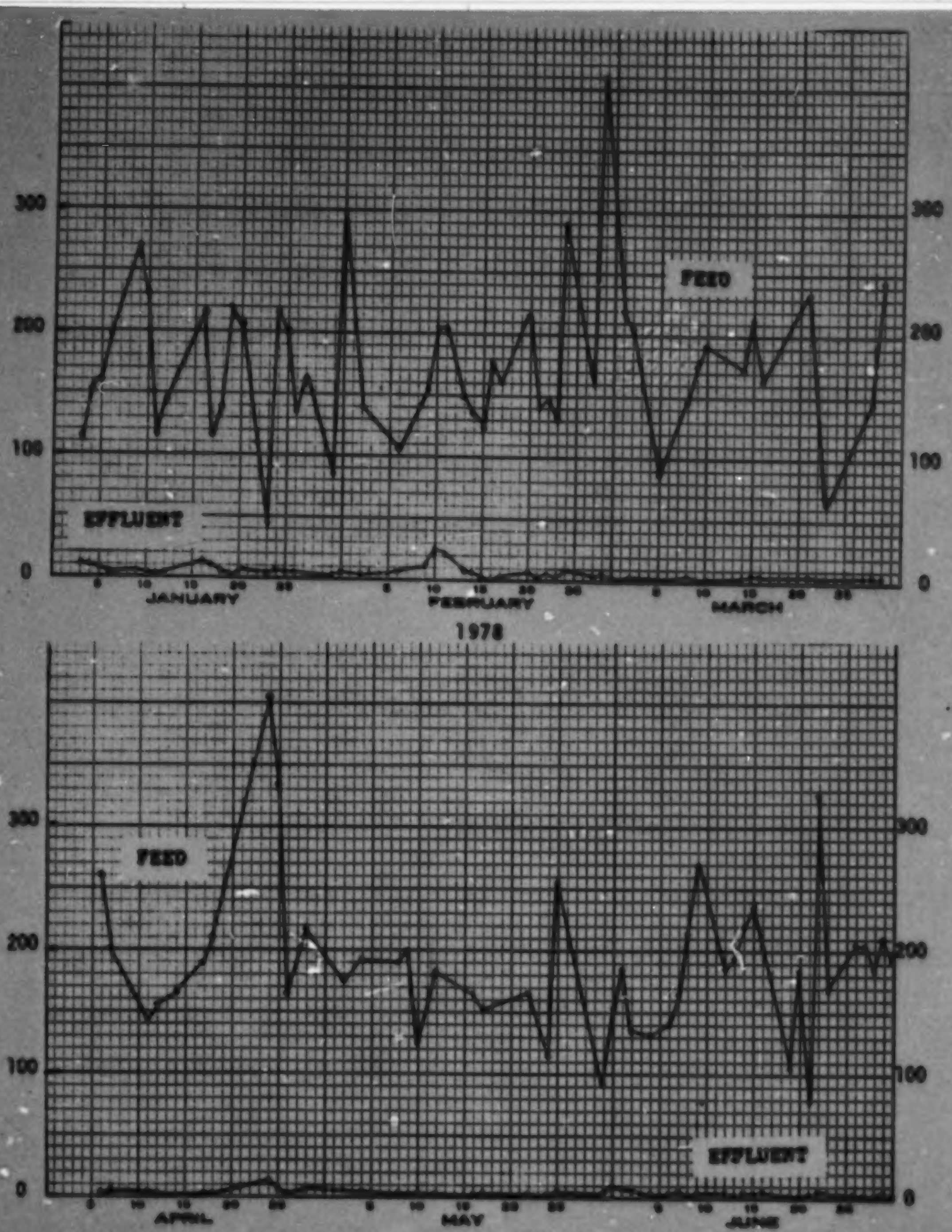

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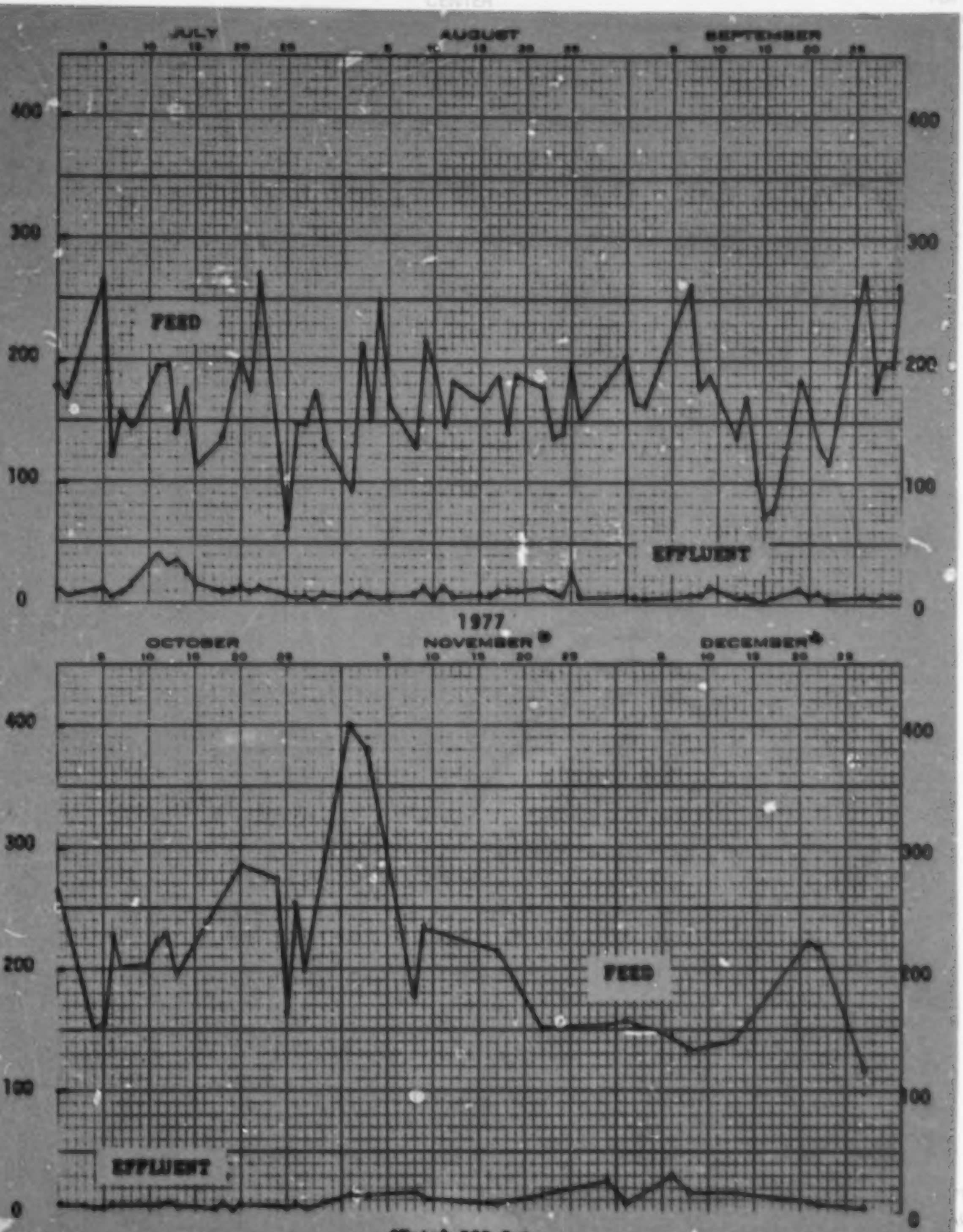

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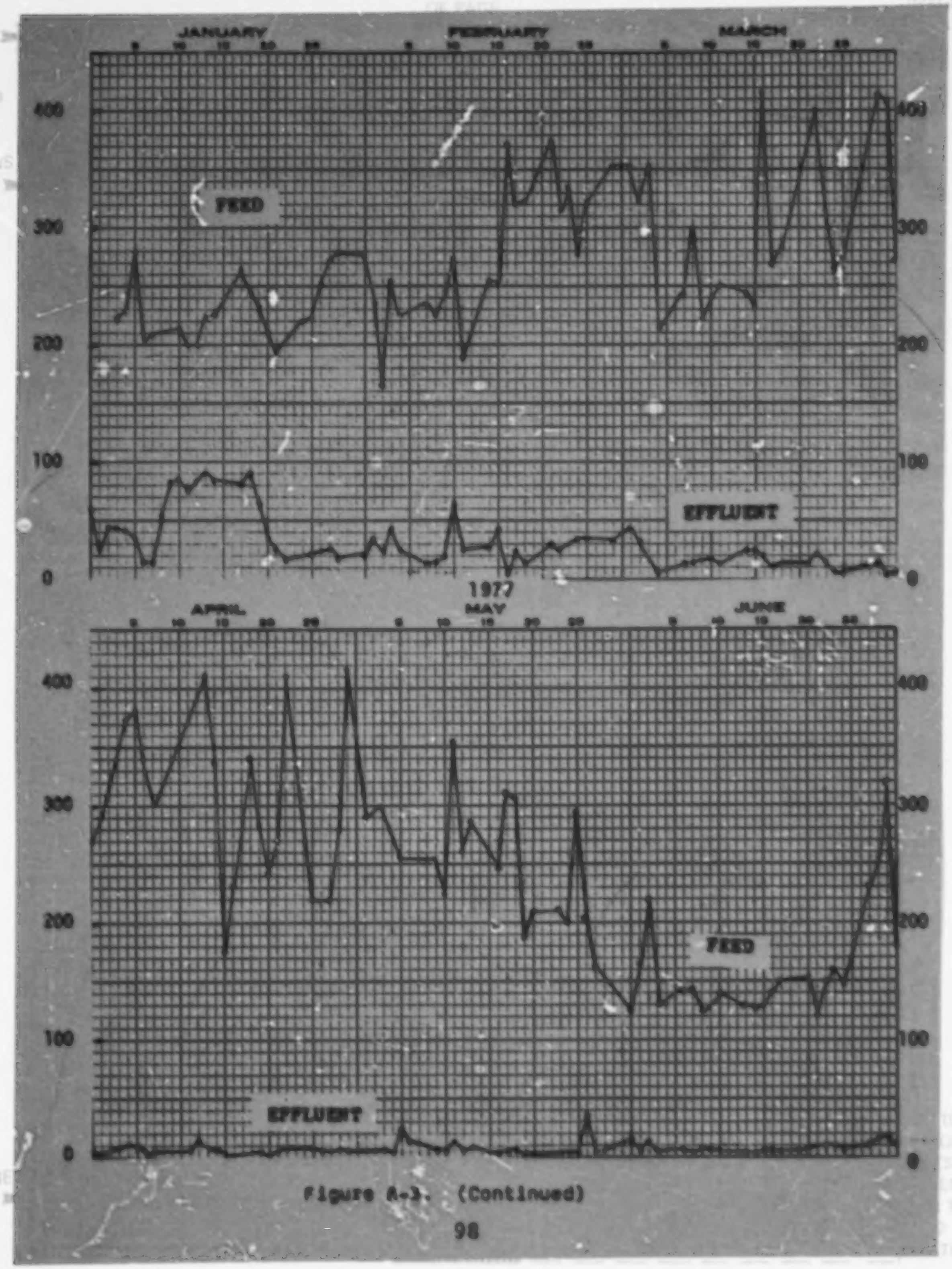

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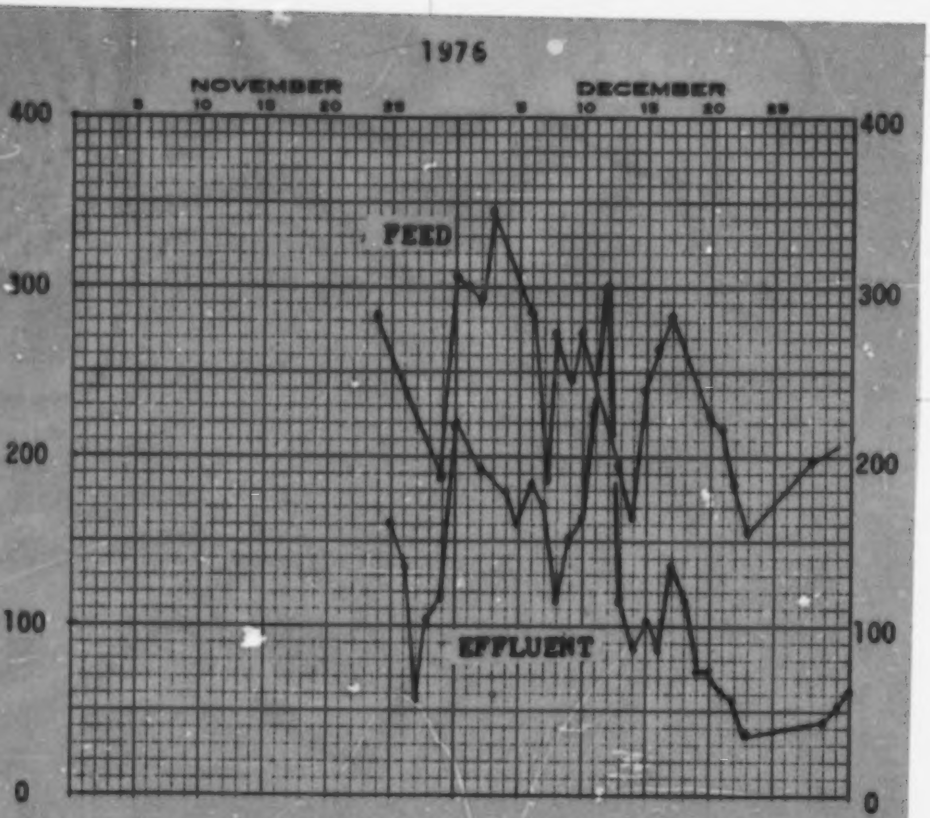

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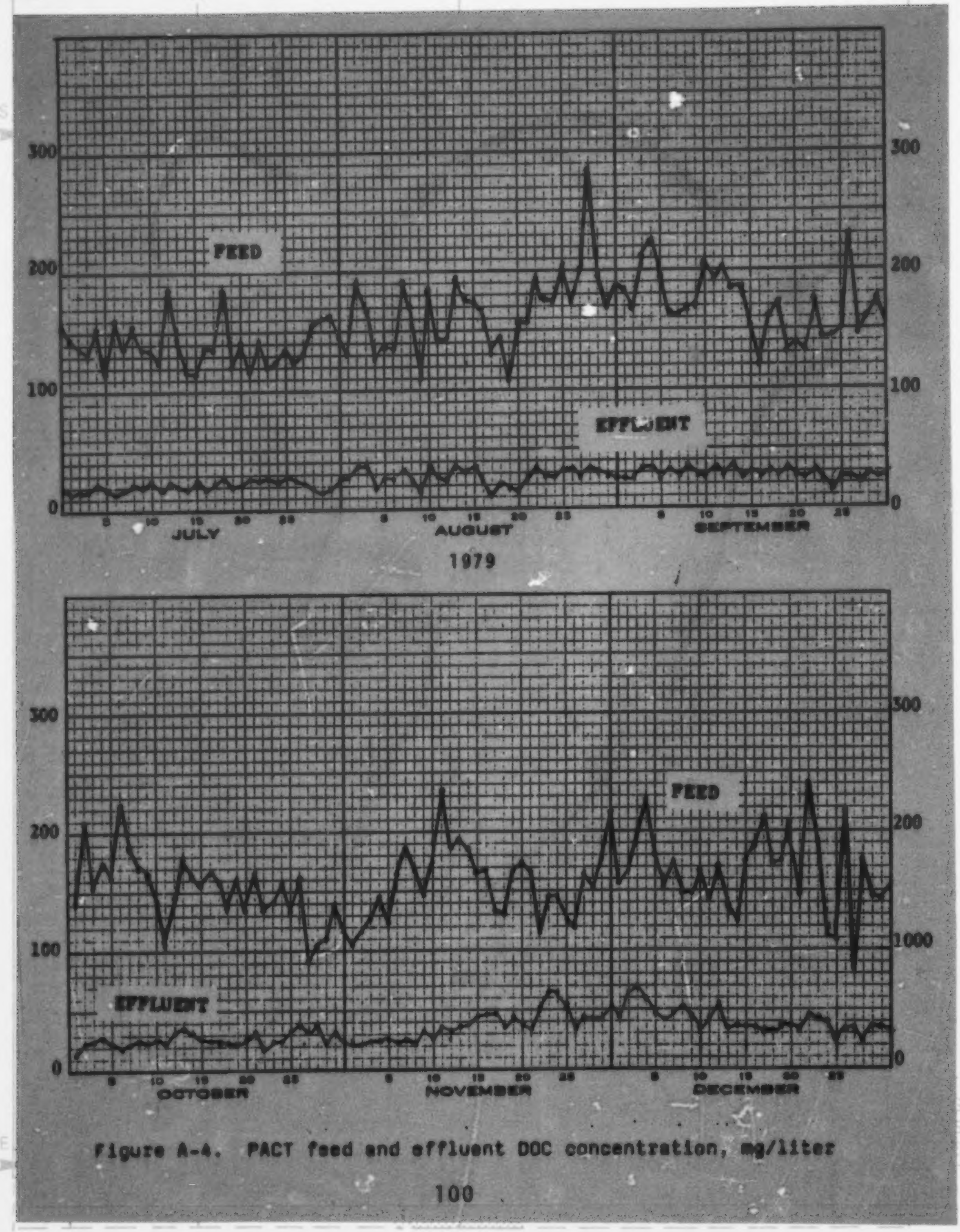

Figure A-4. PACT feed and effluent DOC concentration, mg/liter

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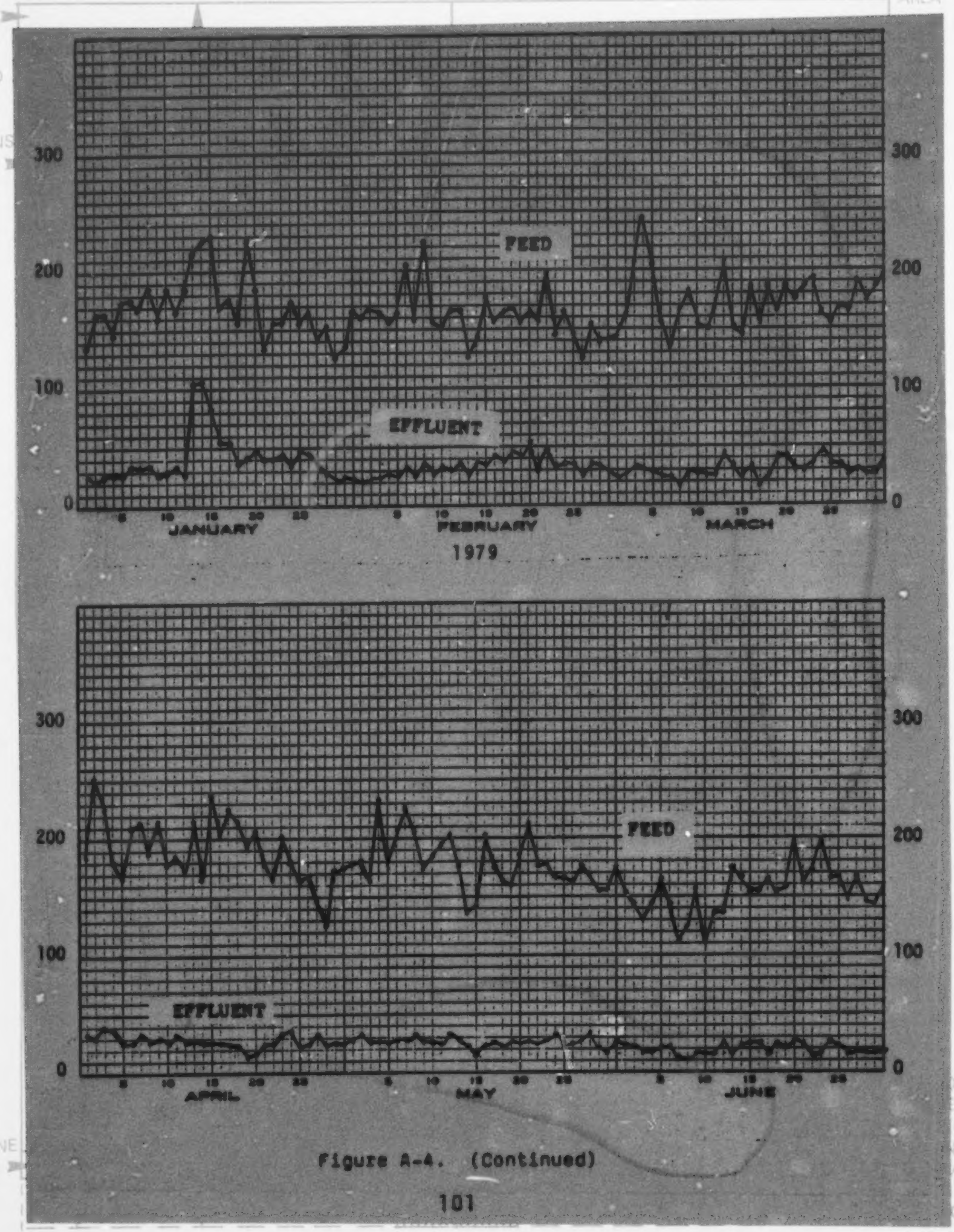

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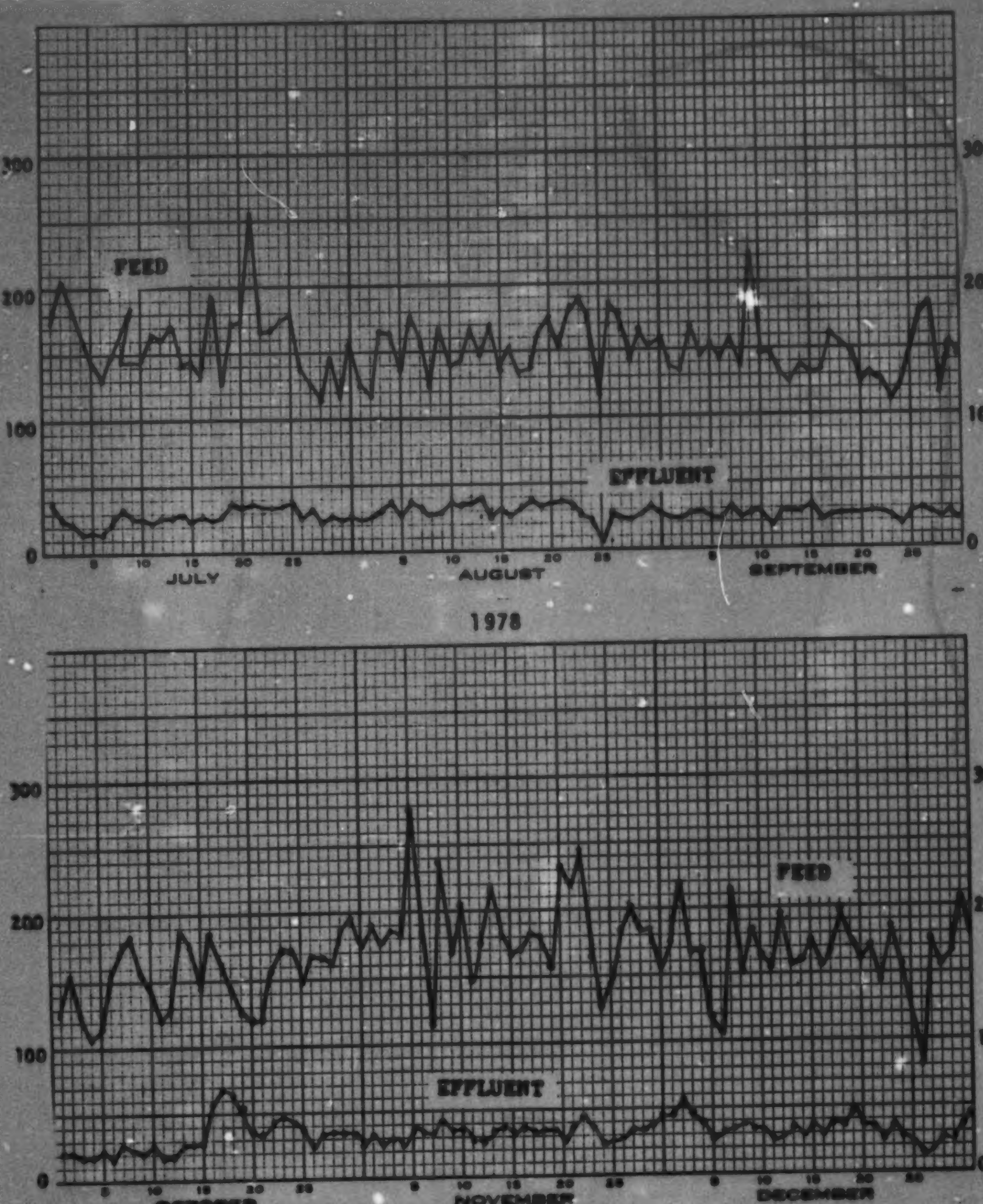

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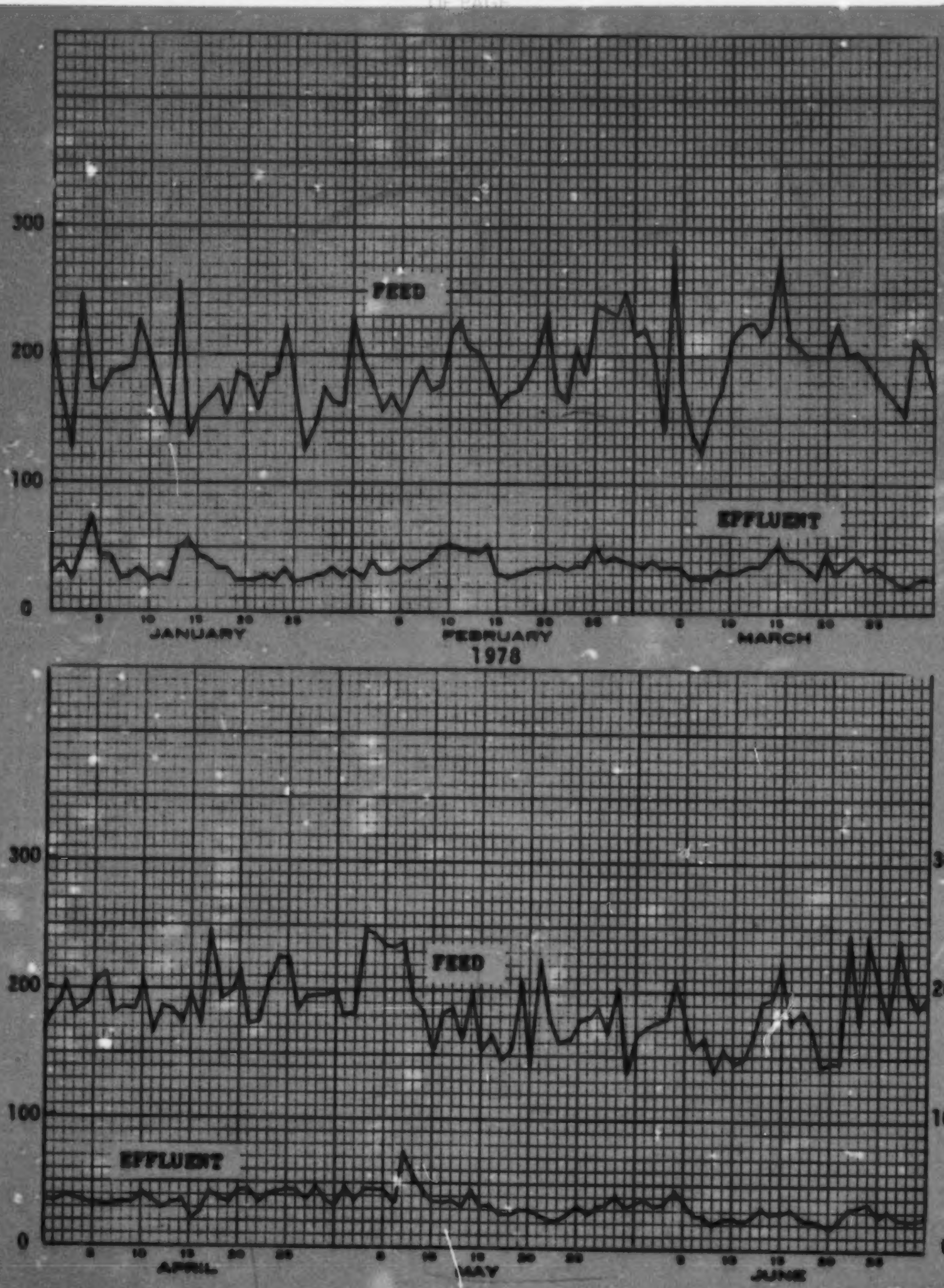

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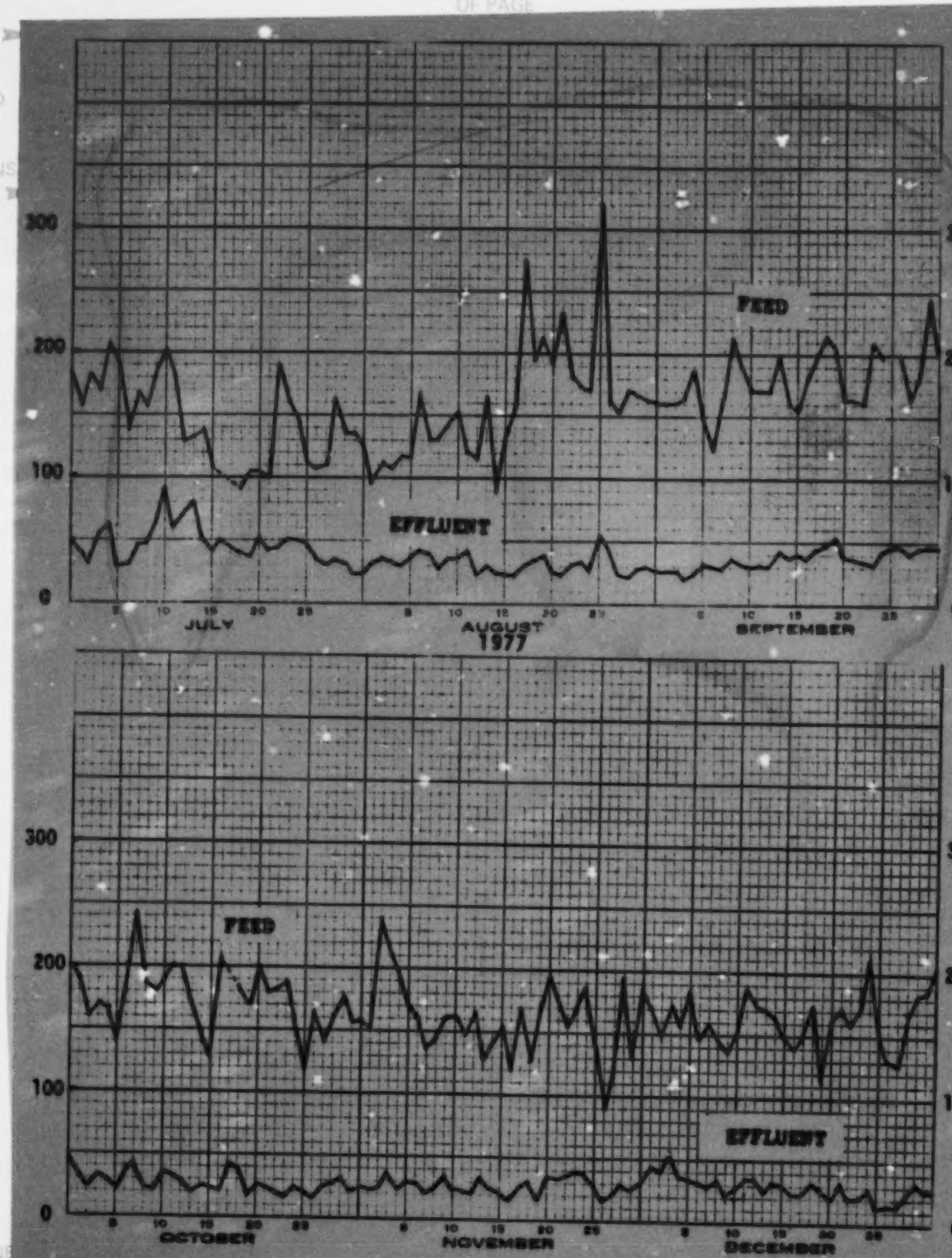

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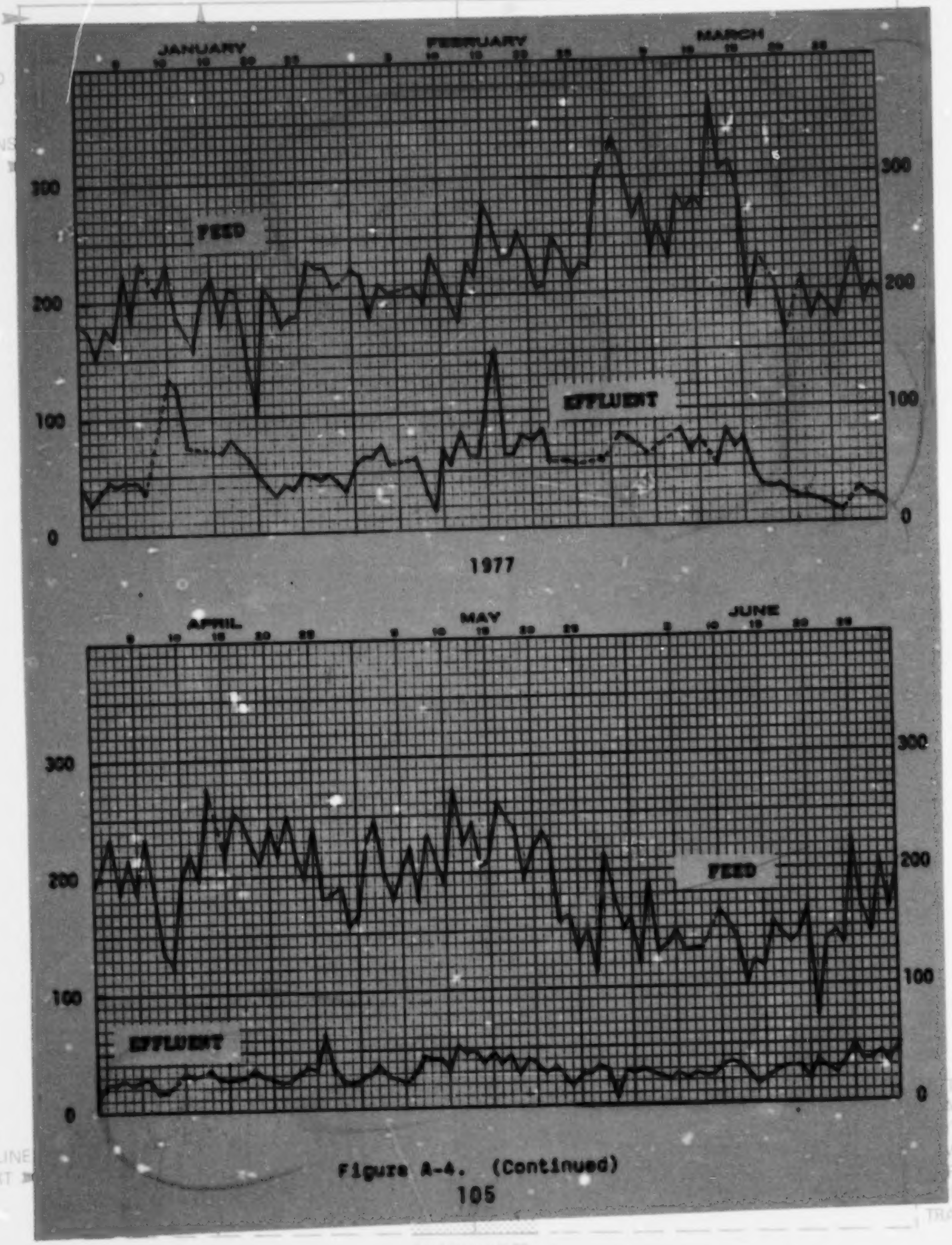

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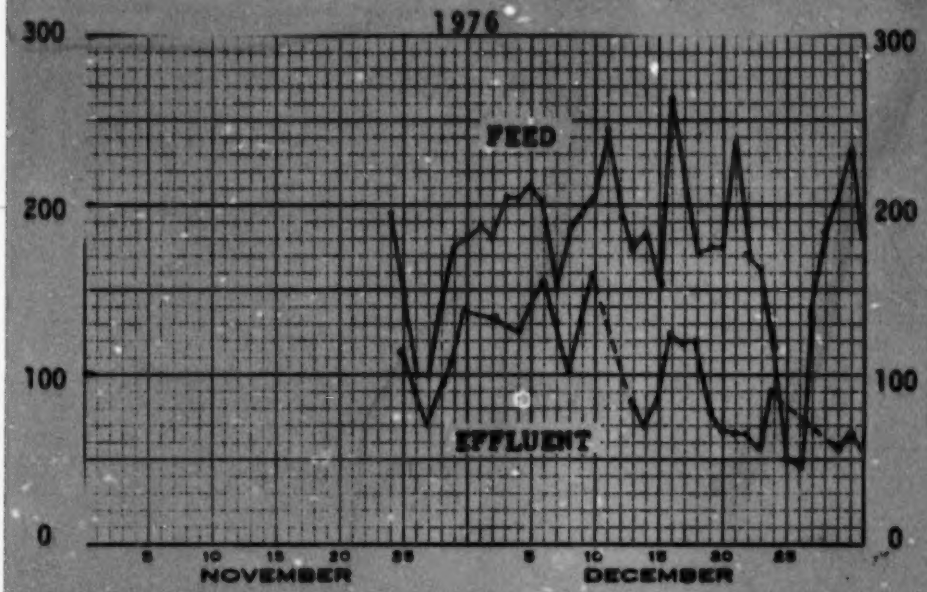

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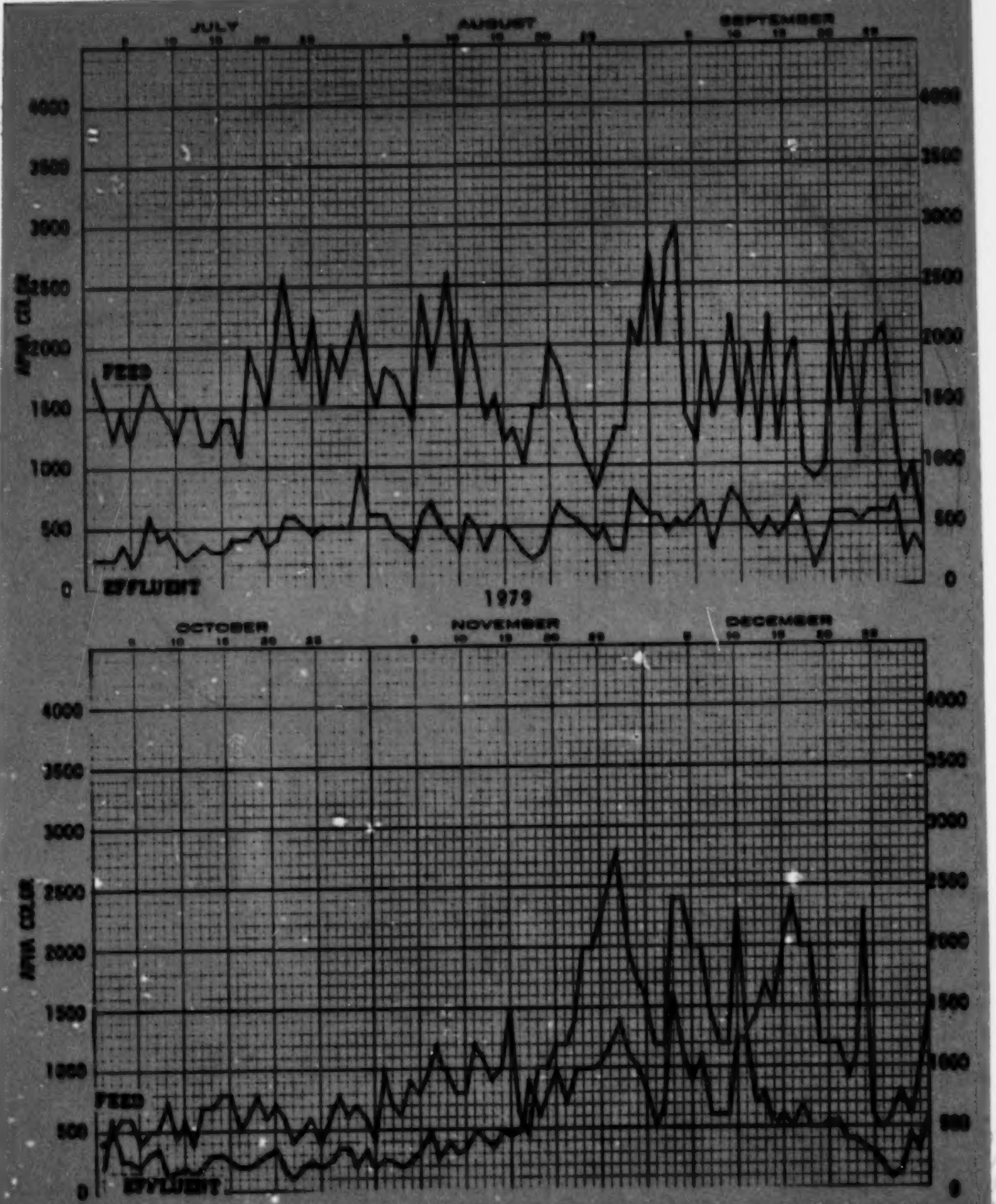

Figure A-5. PACT feed and effluent color, APHA units

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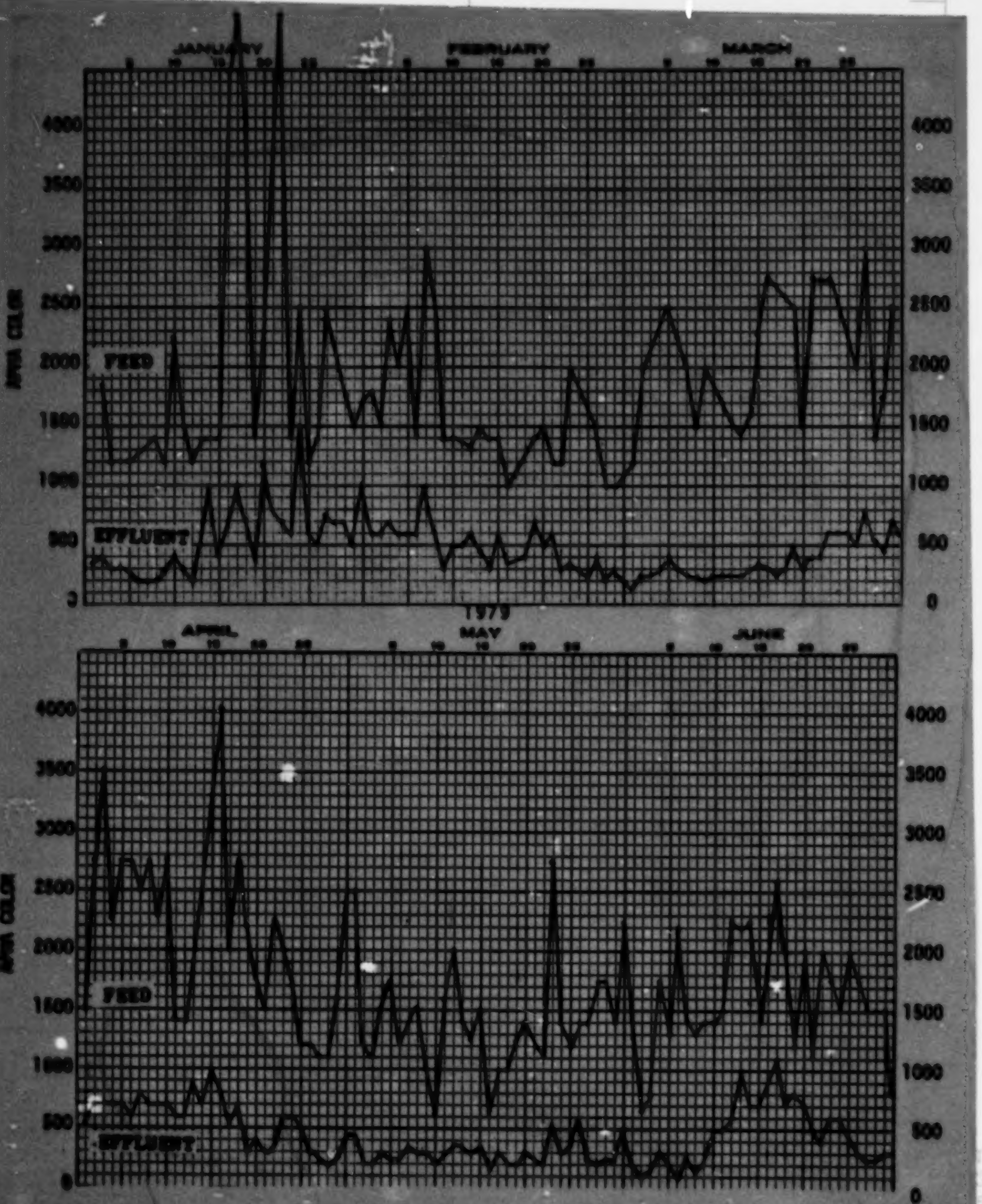

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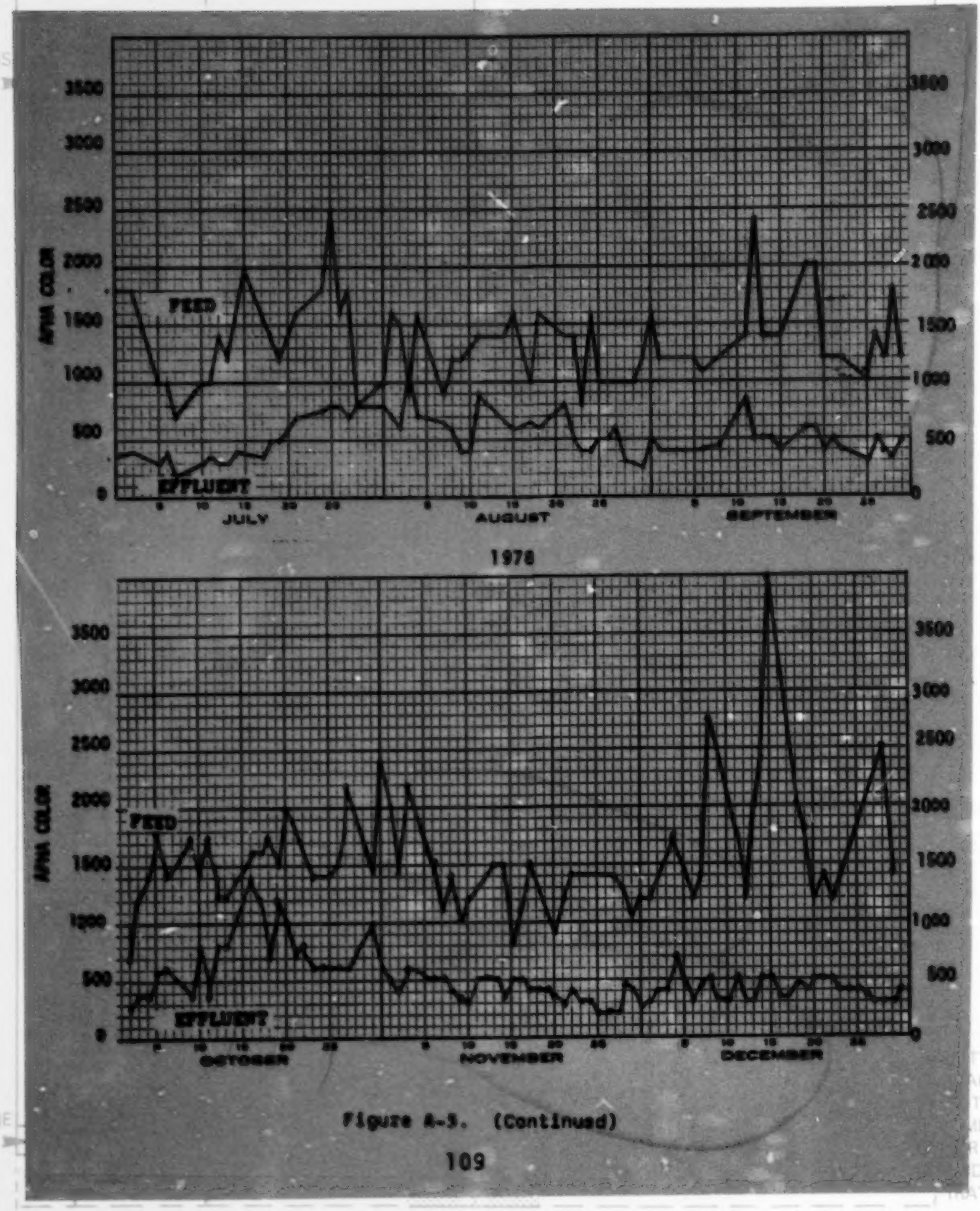

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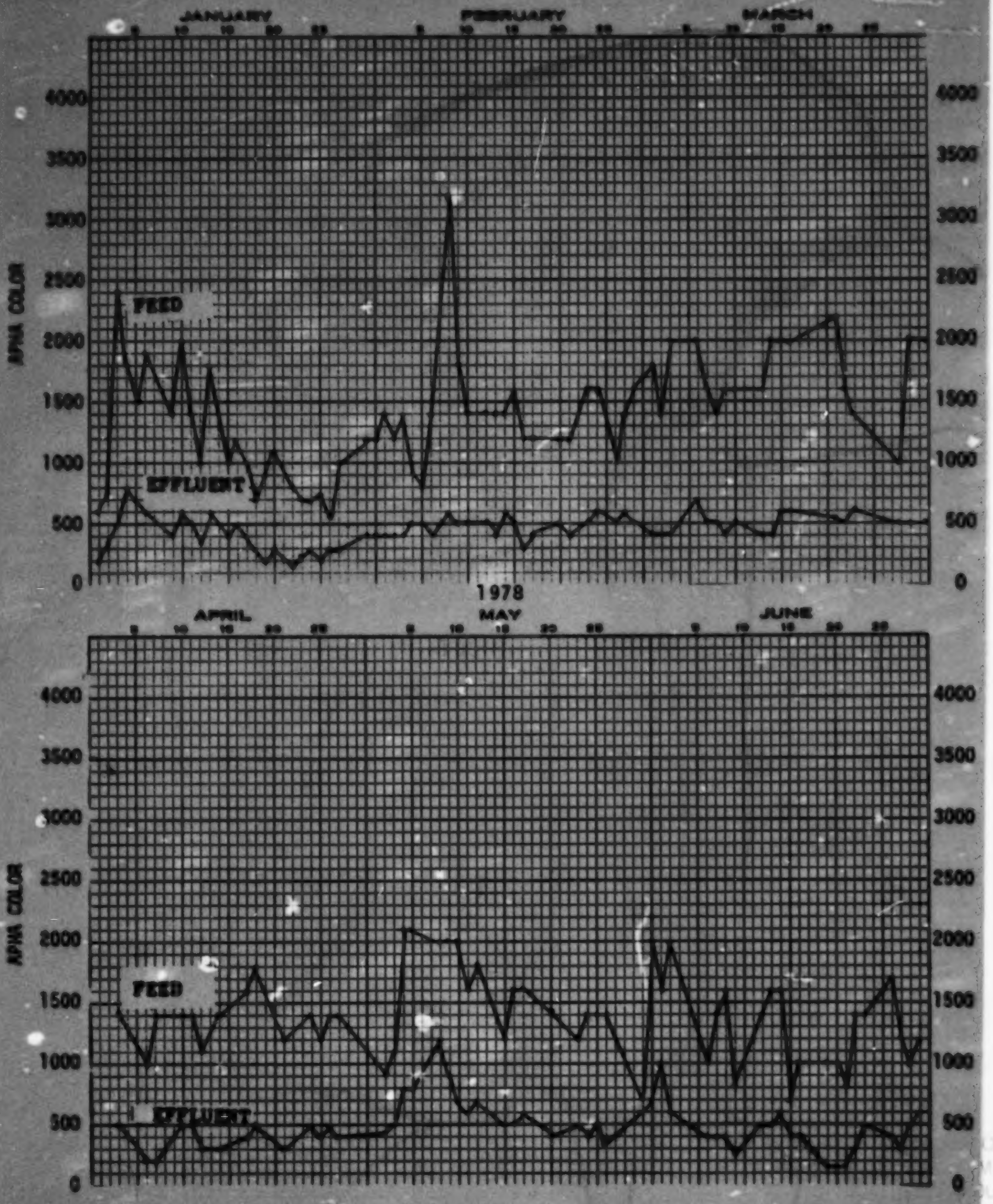

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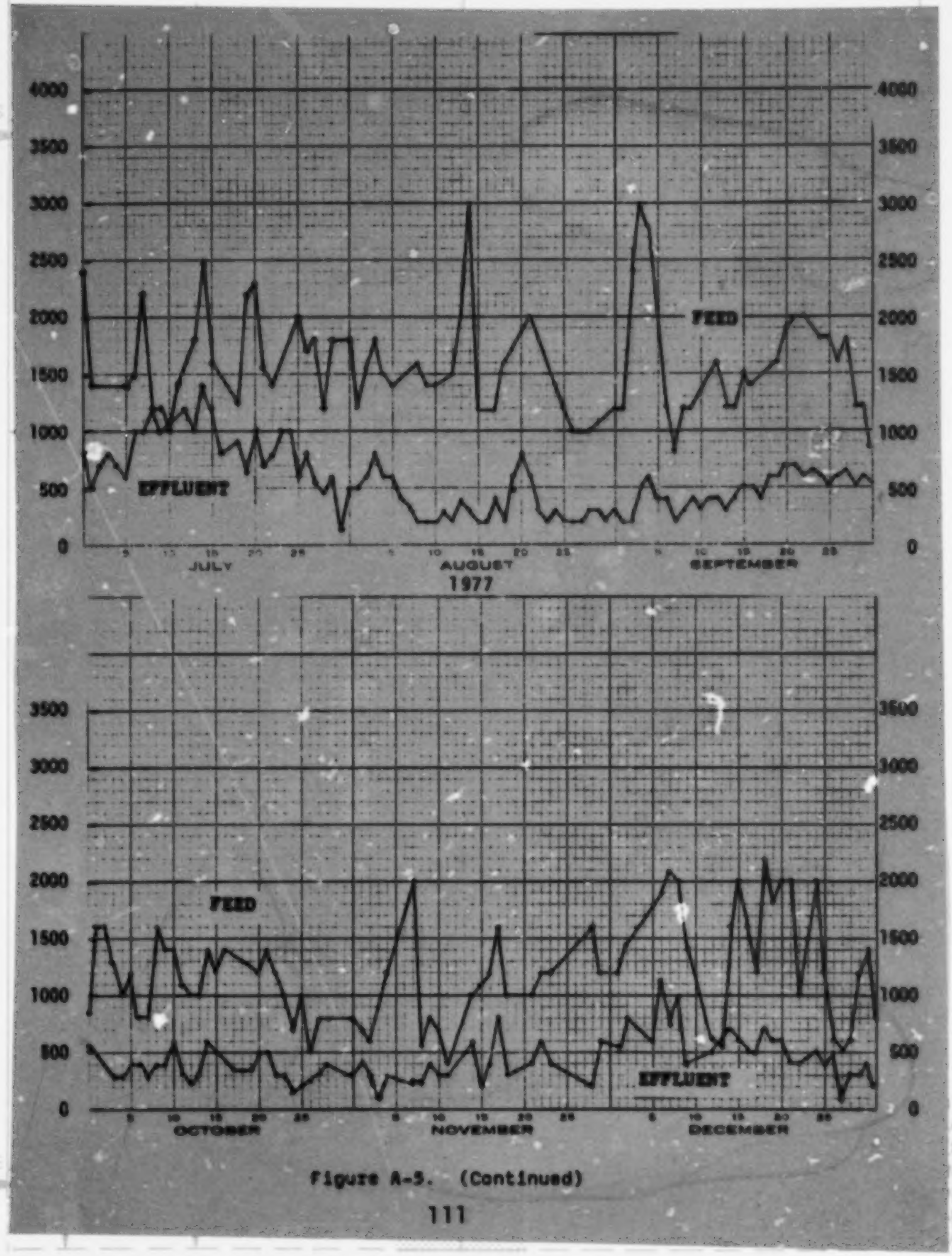

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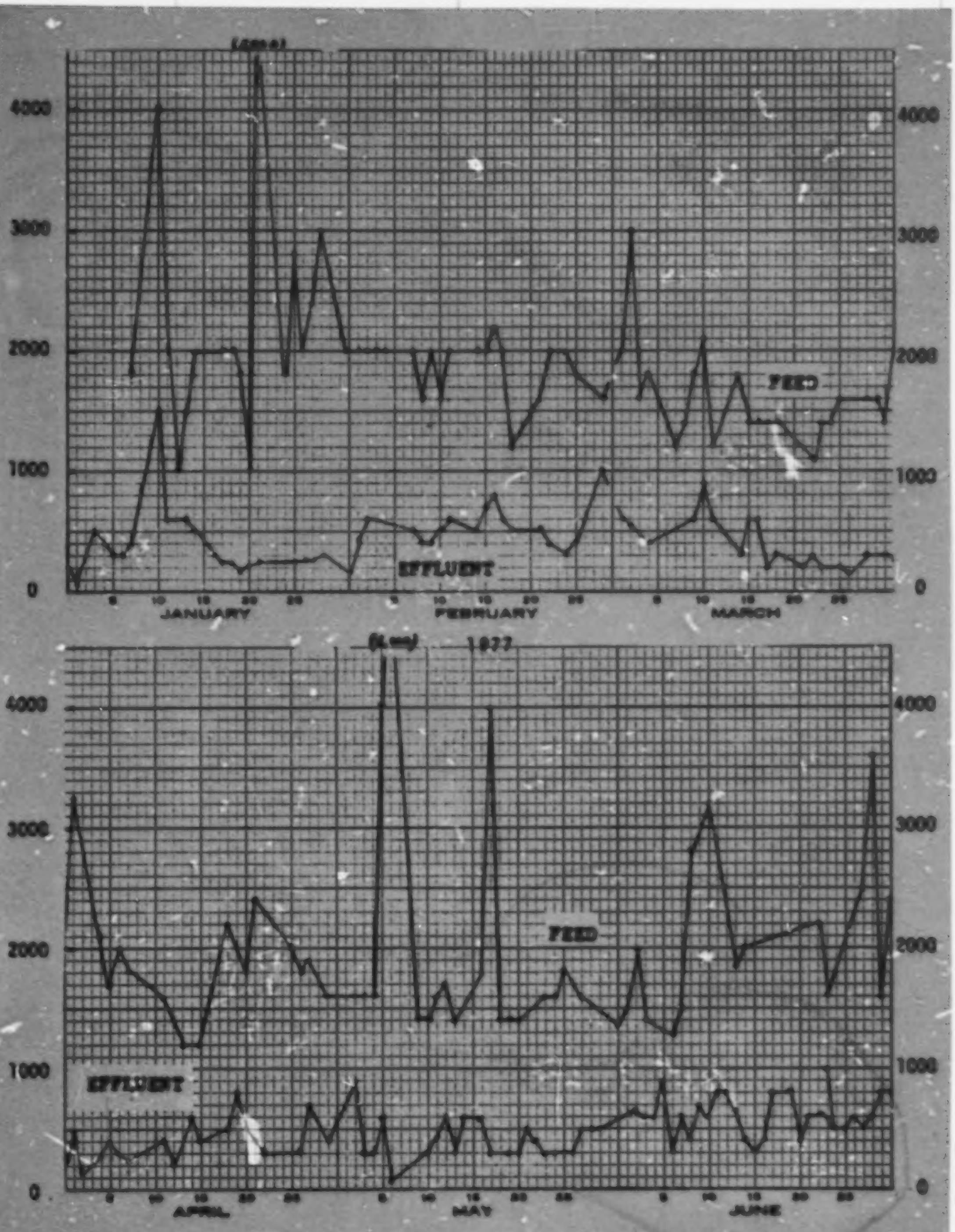

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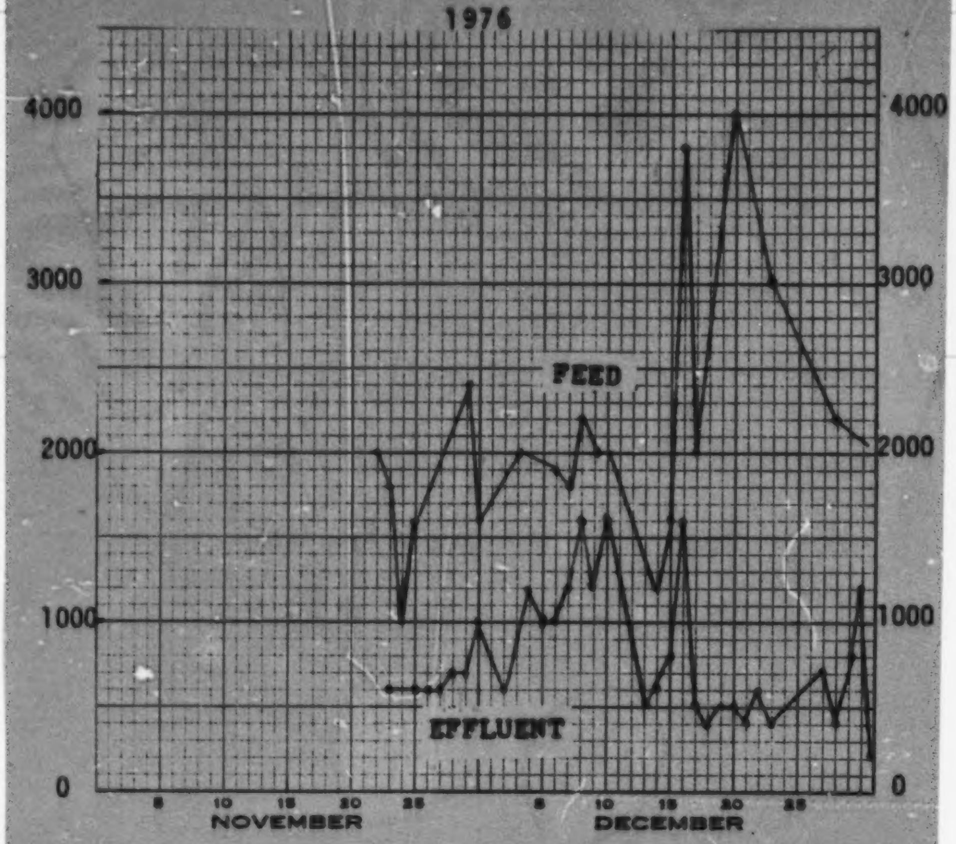

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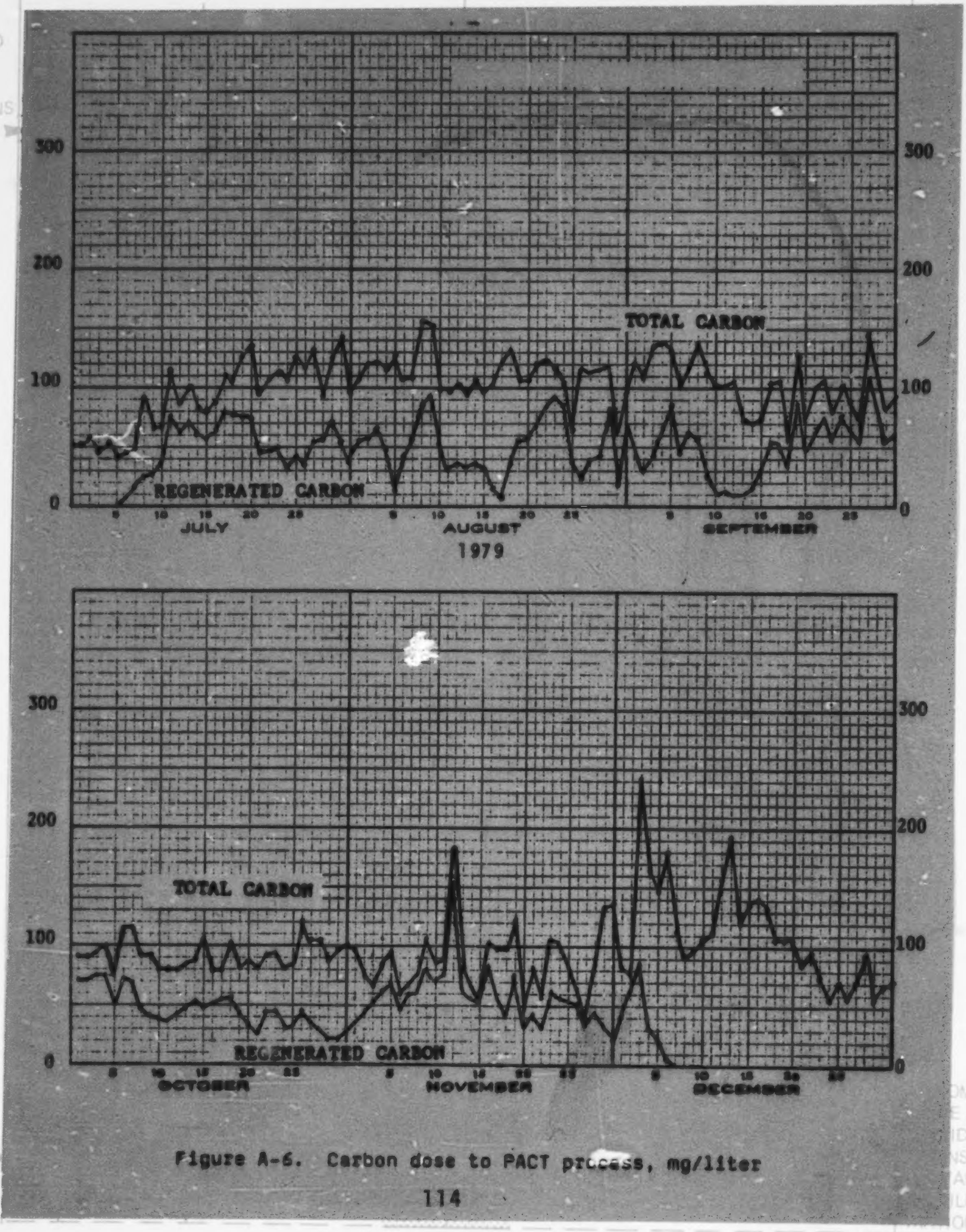

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Figure A-6. Carbon dose to PACT process, mg/liter

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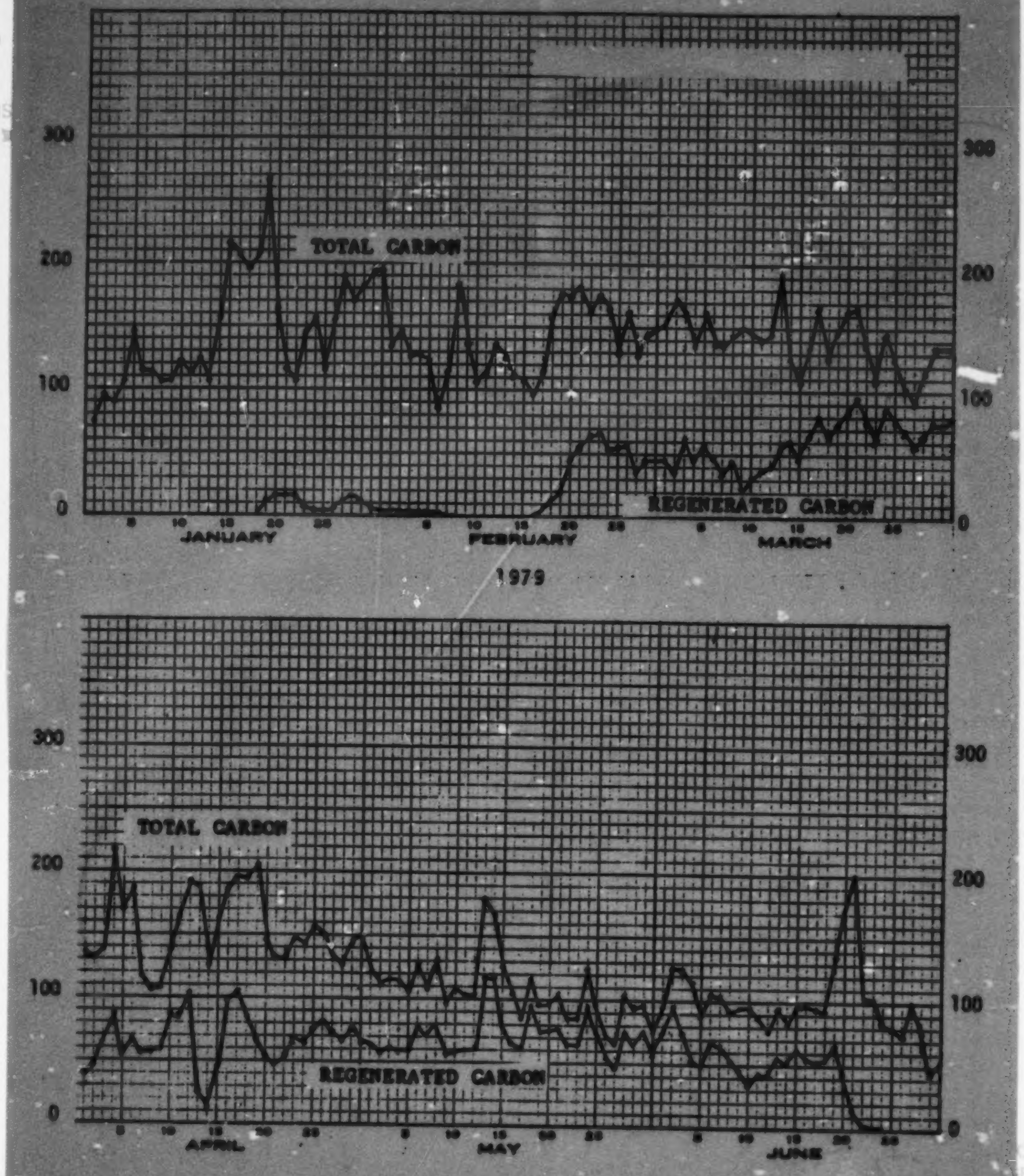

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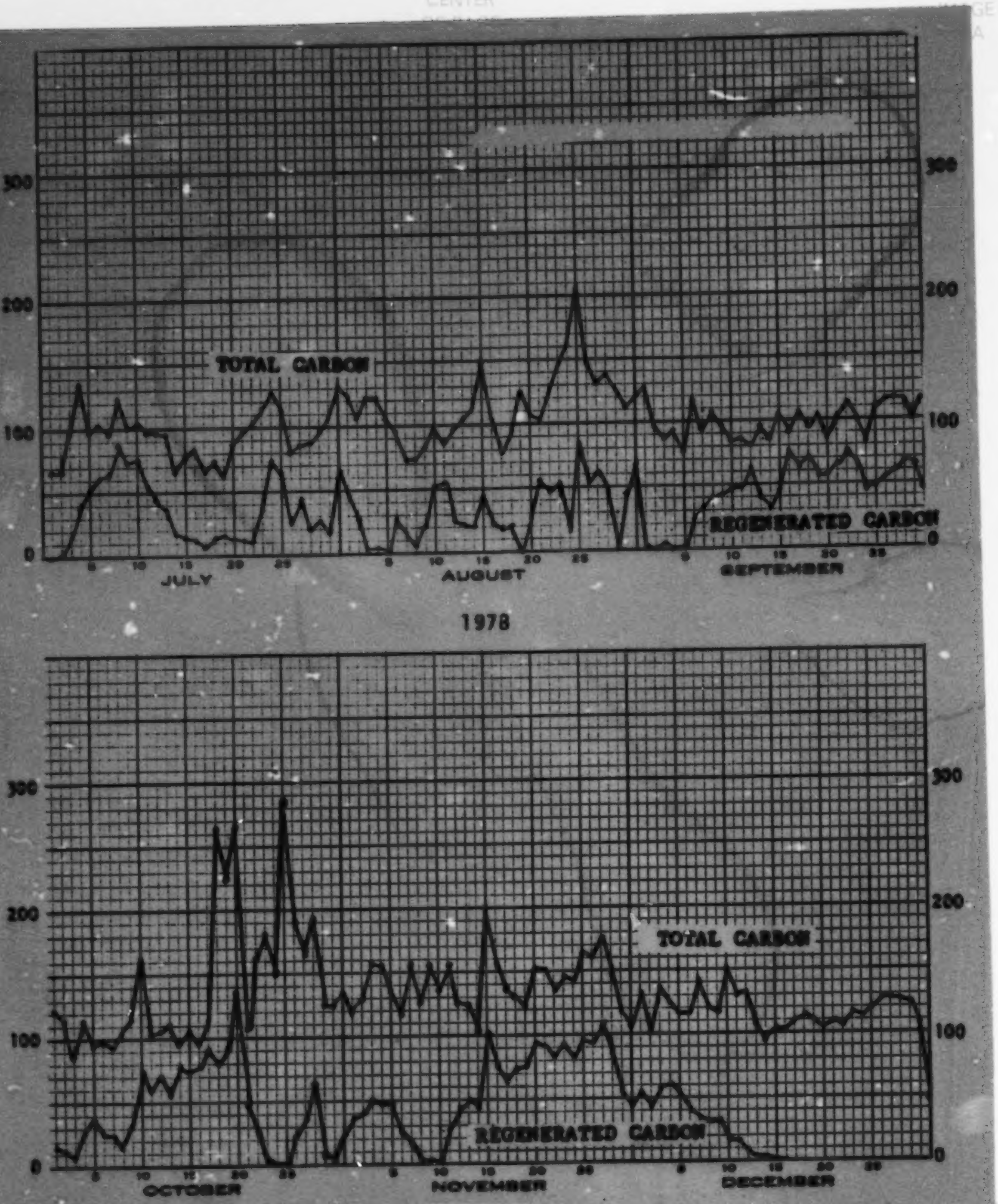

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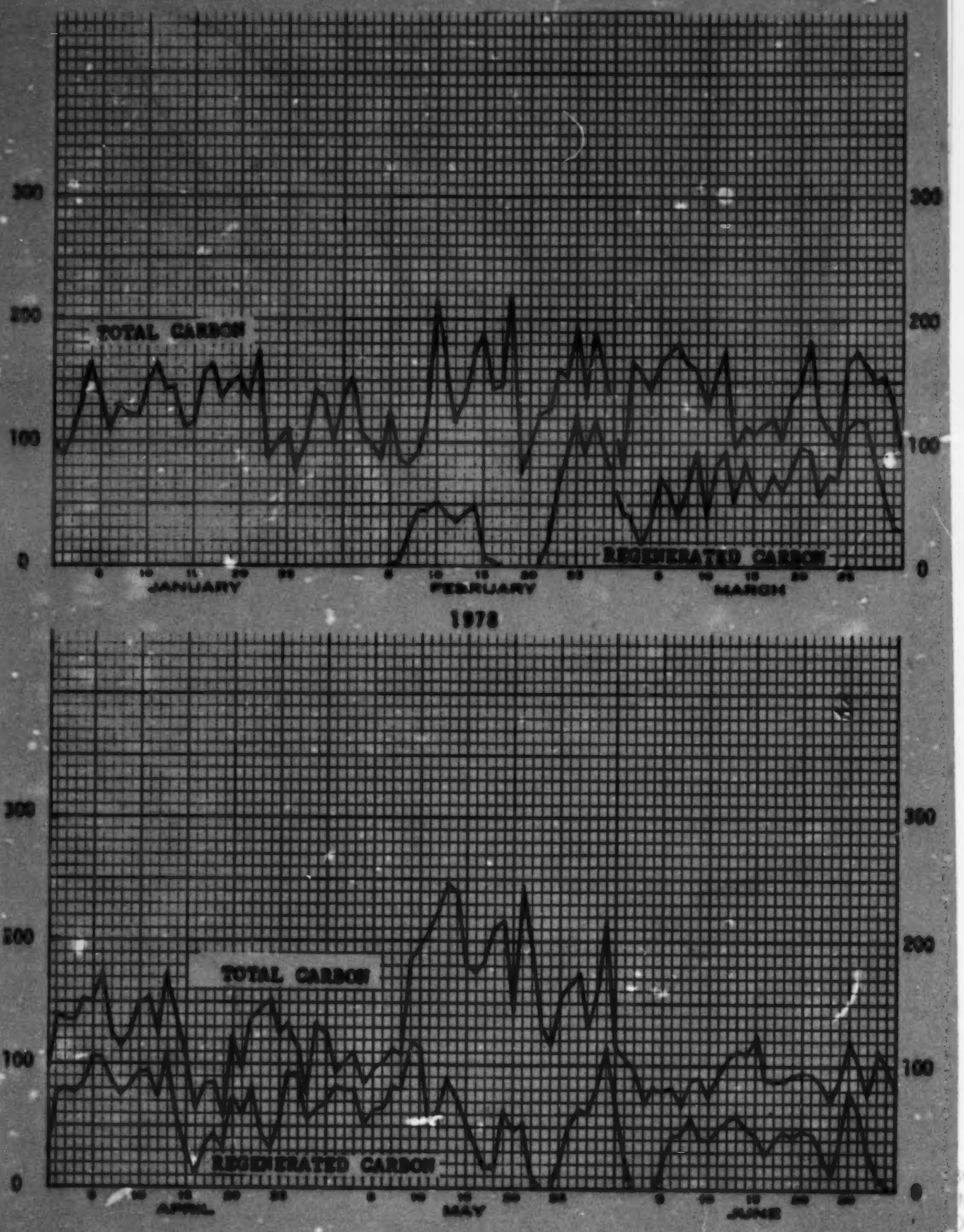

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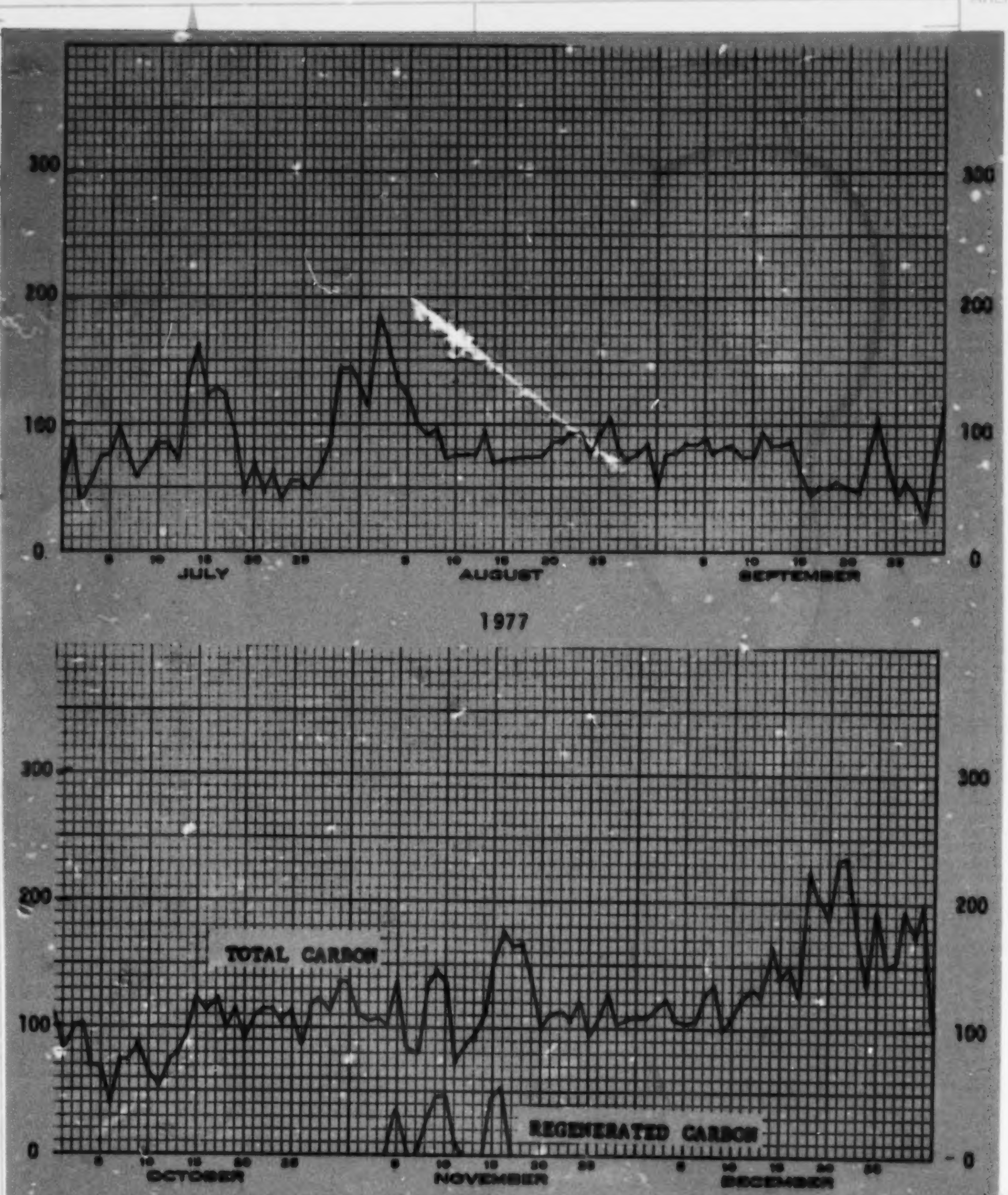

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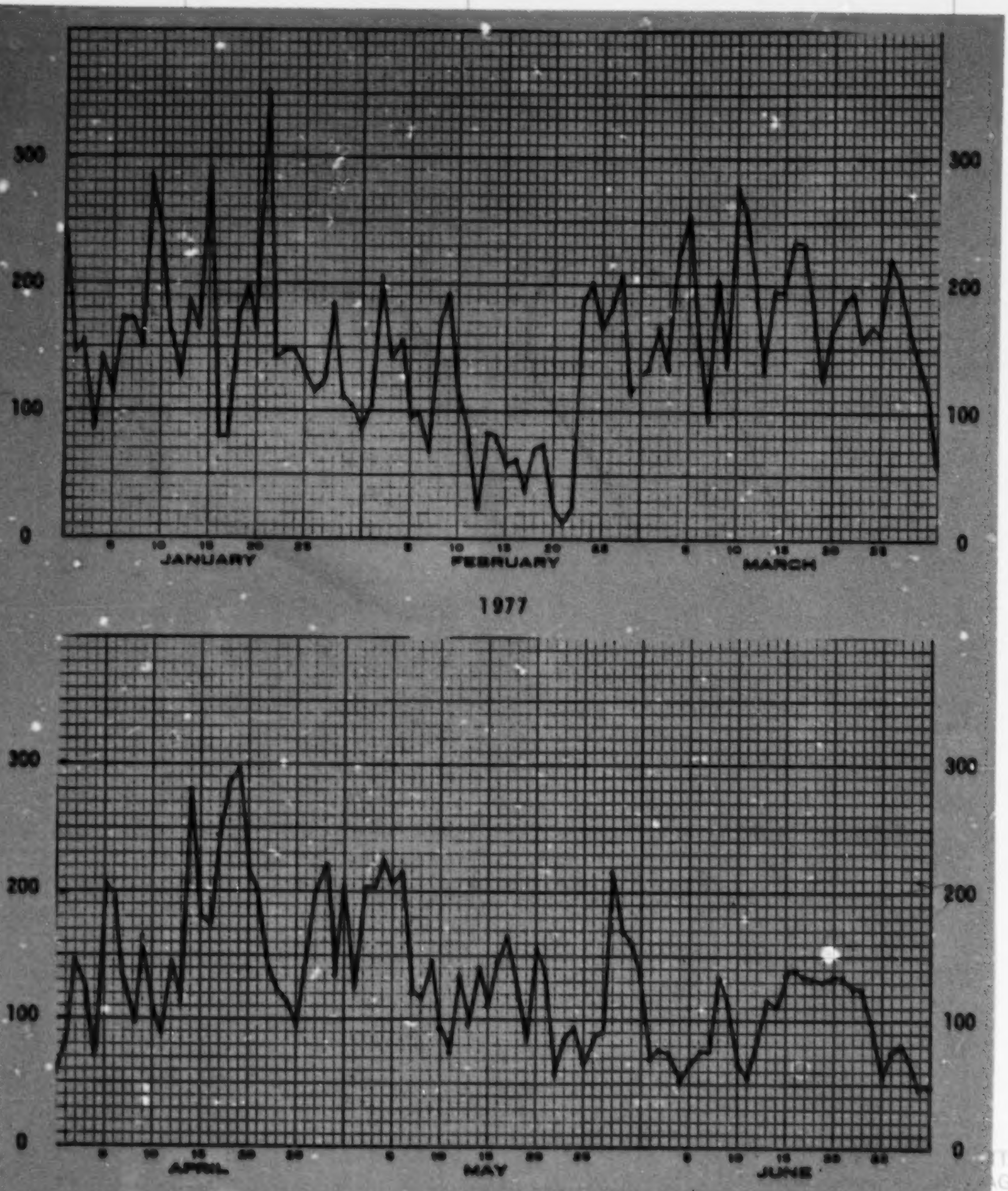

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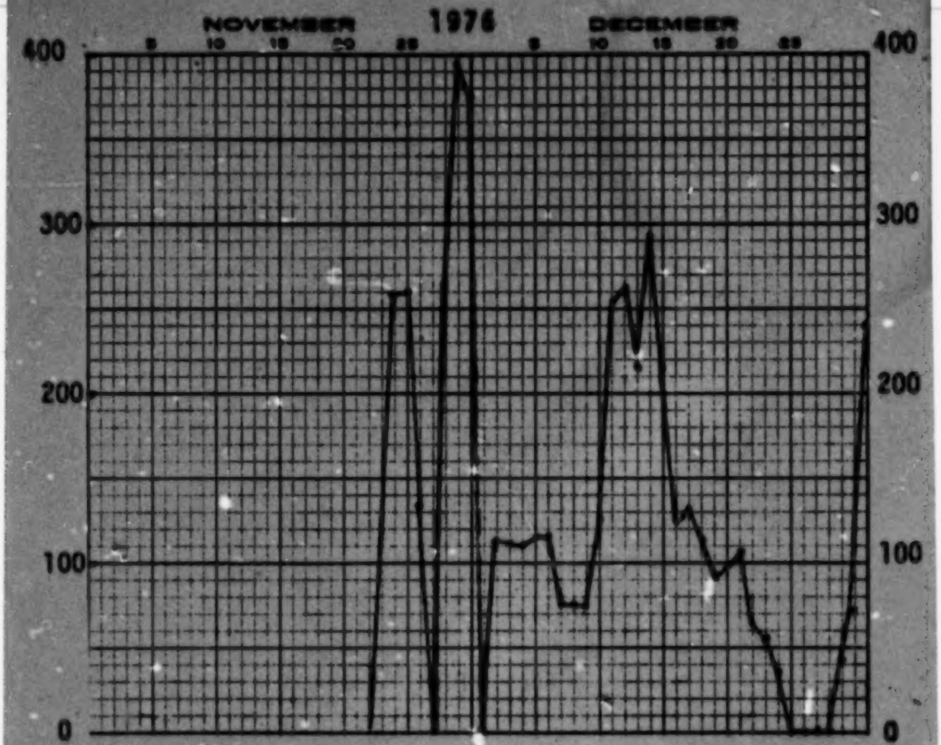

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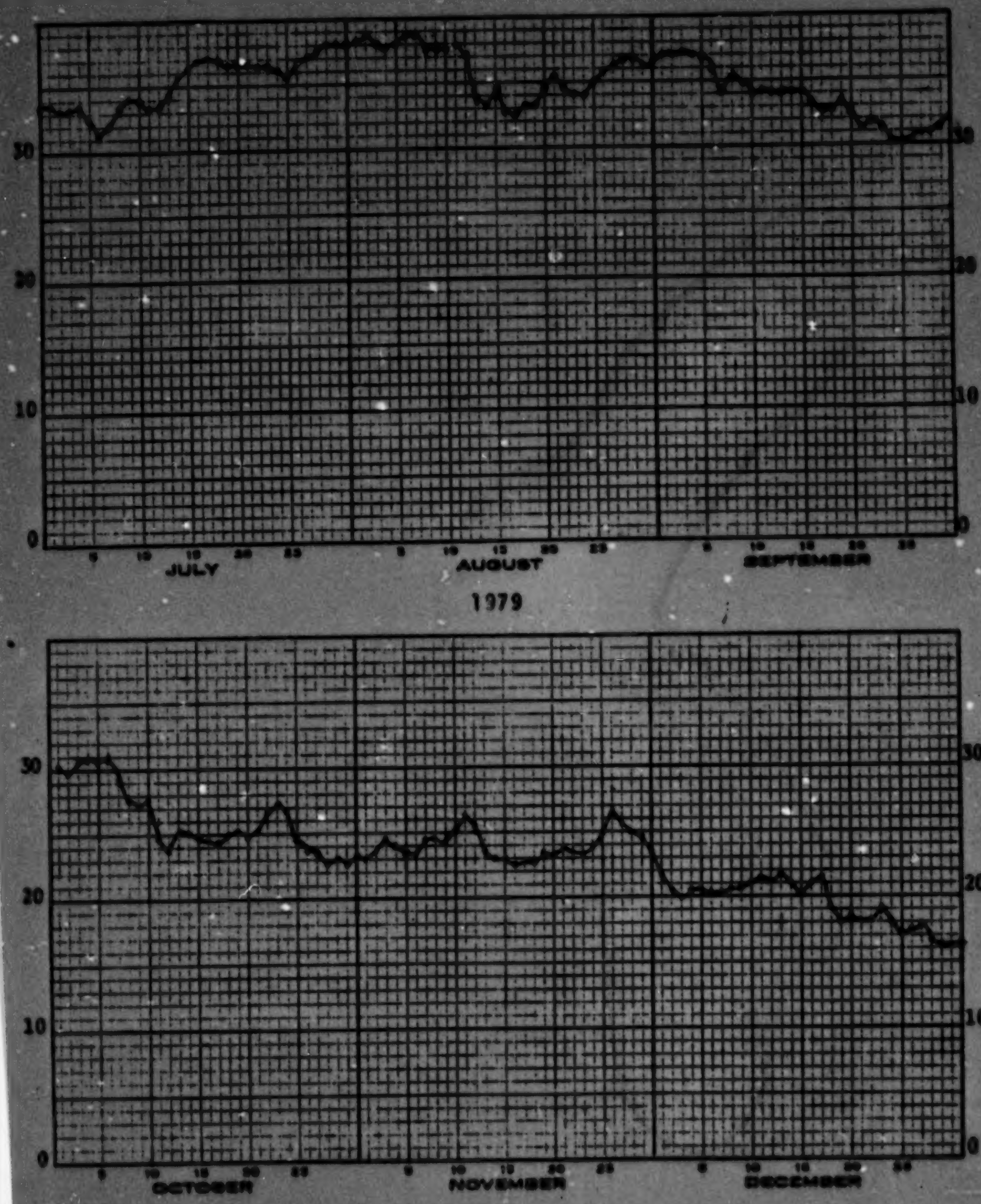

Figure A-7. Aerator temperature, °C.

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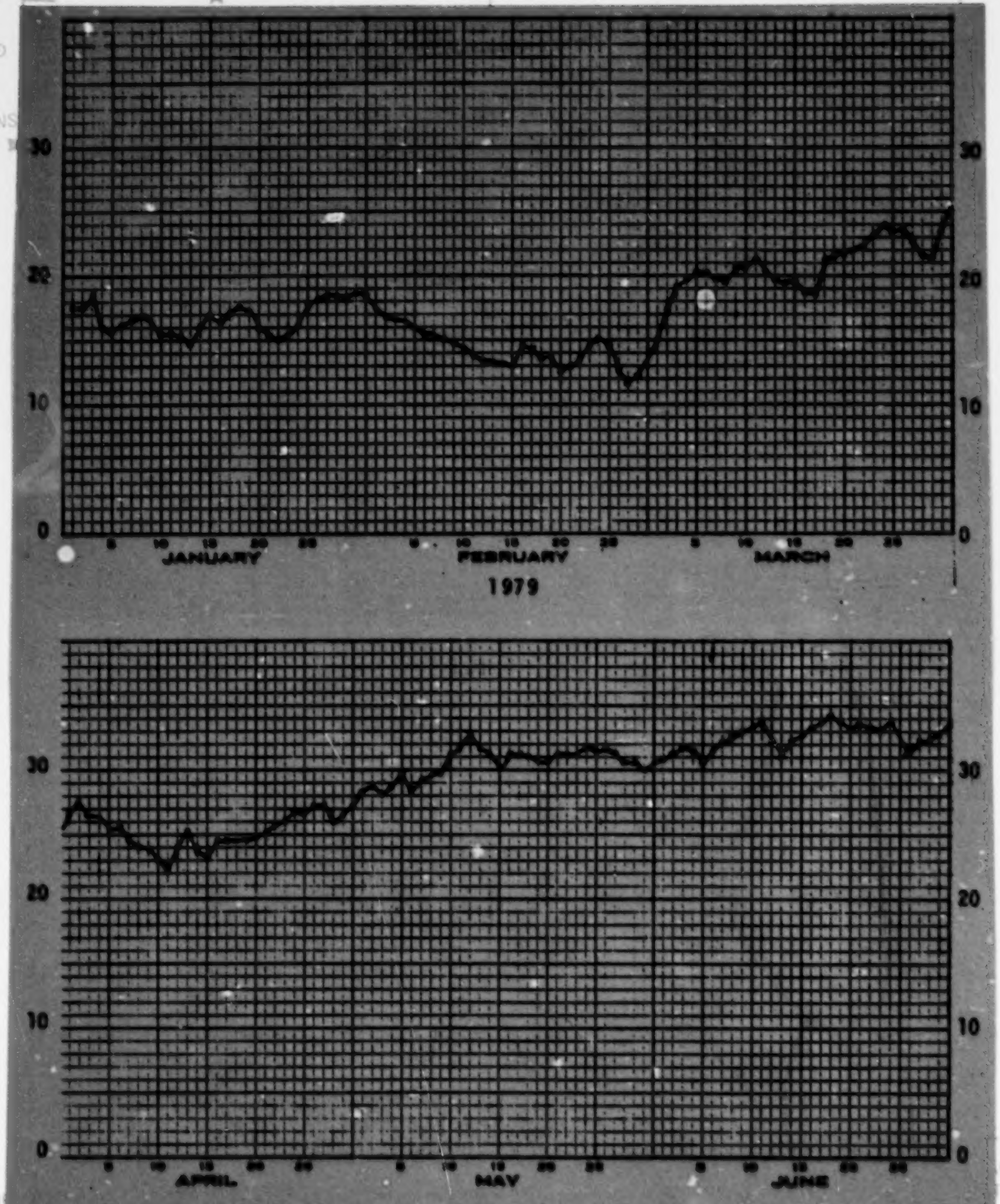

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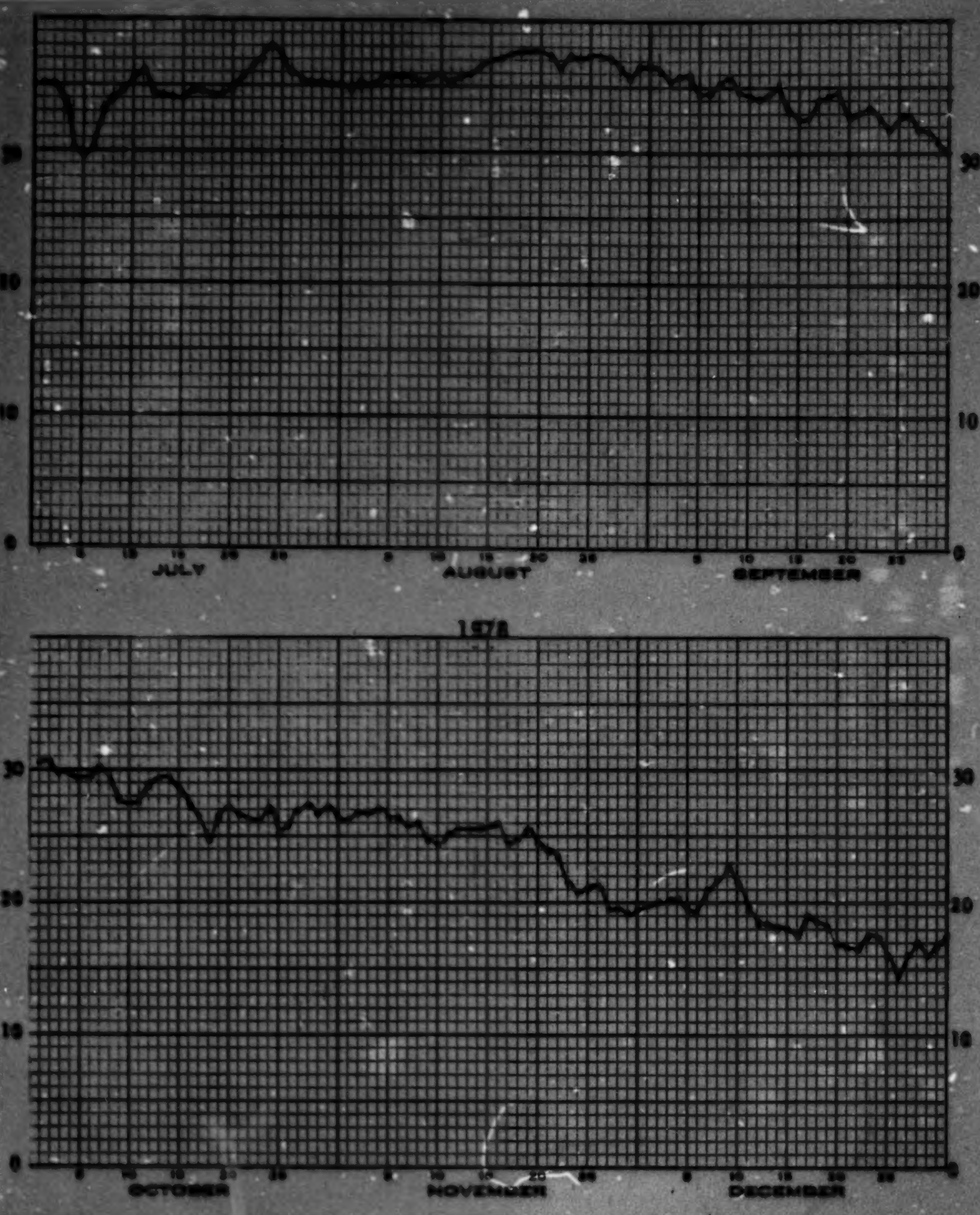

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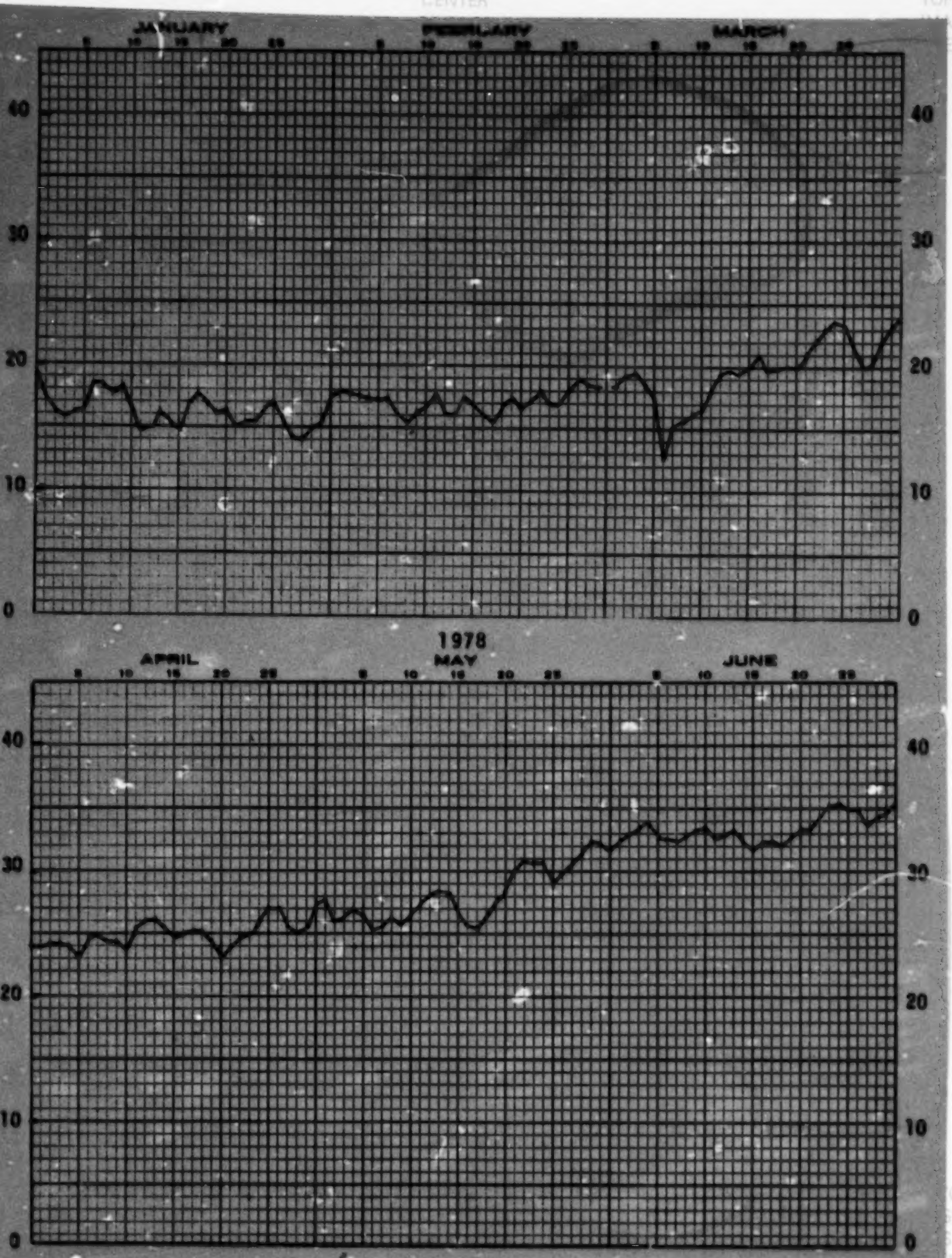

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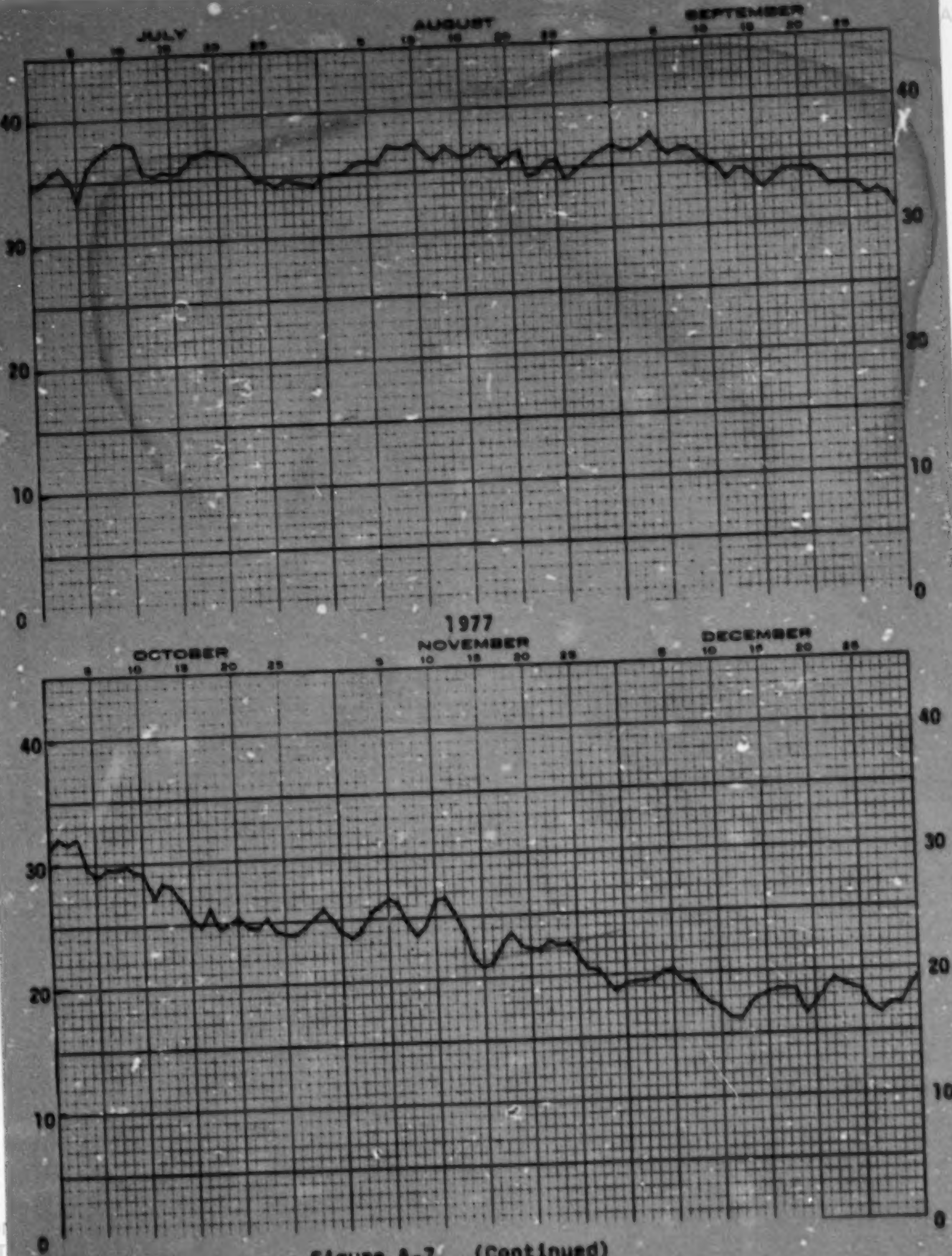

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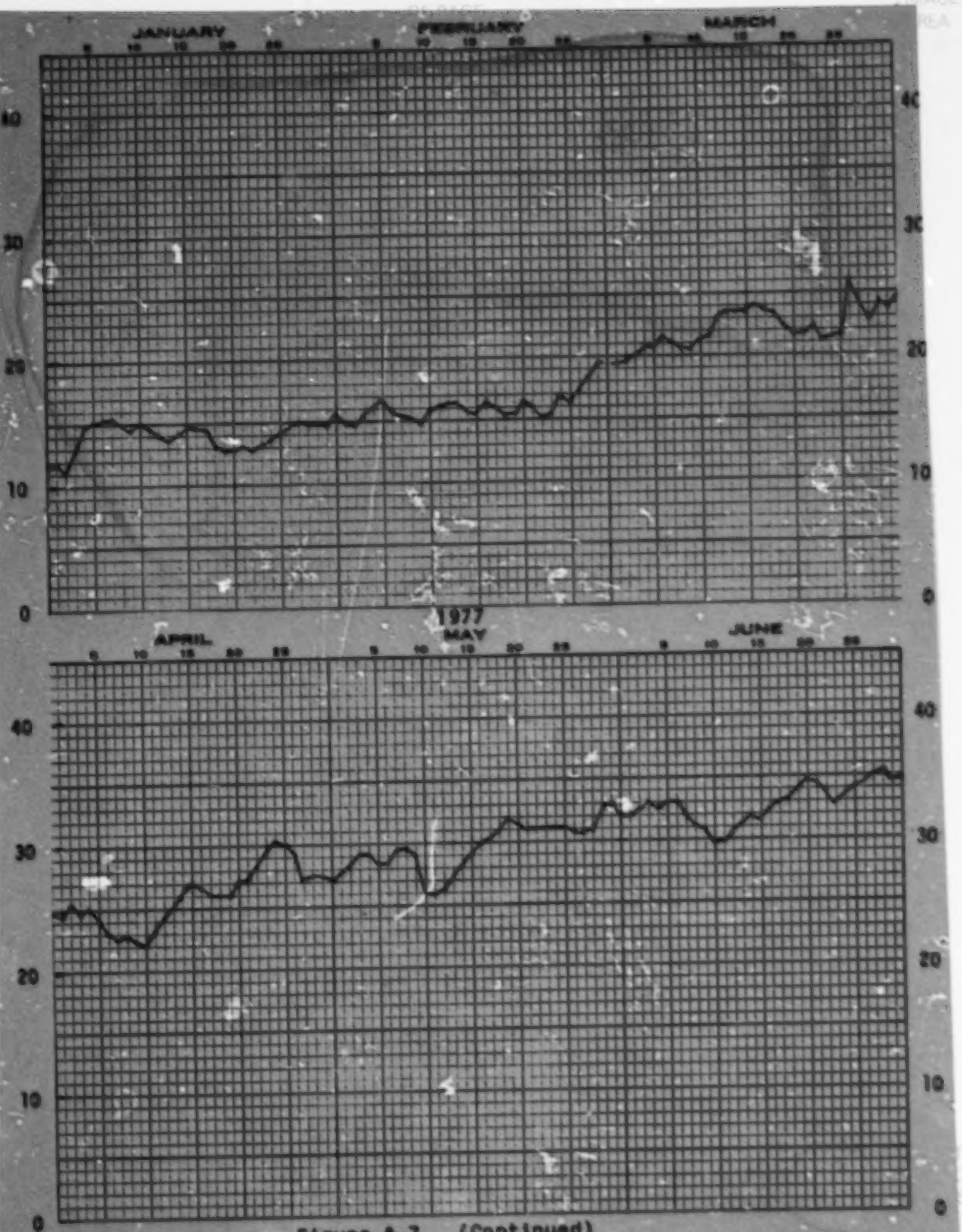

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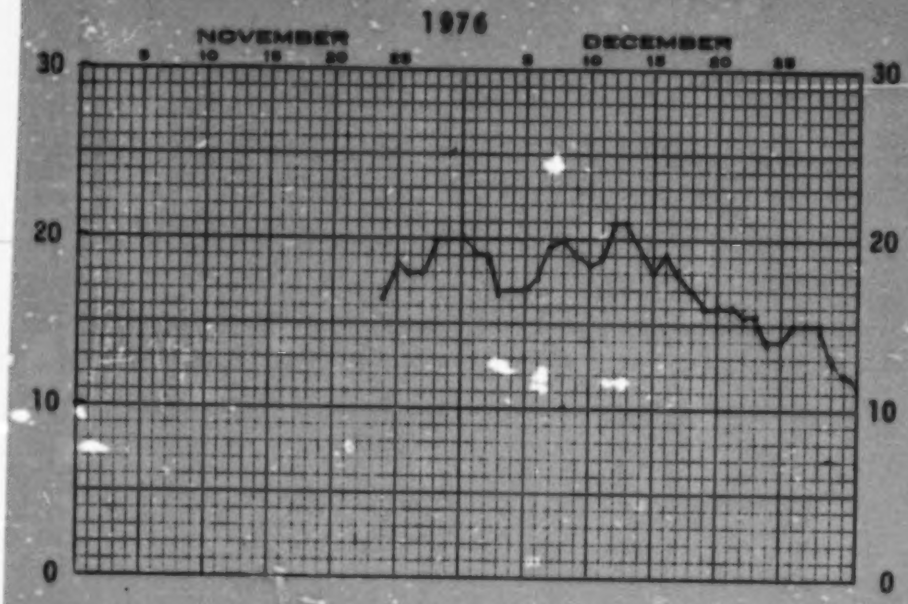

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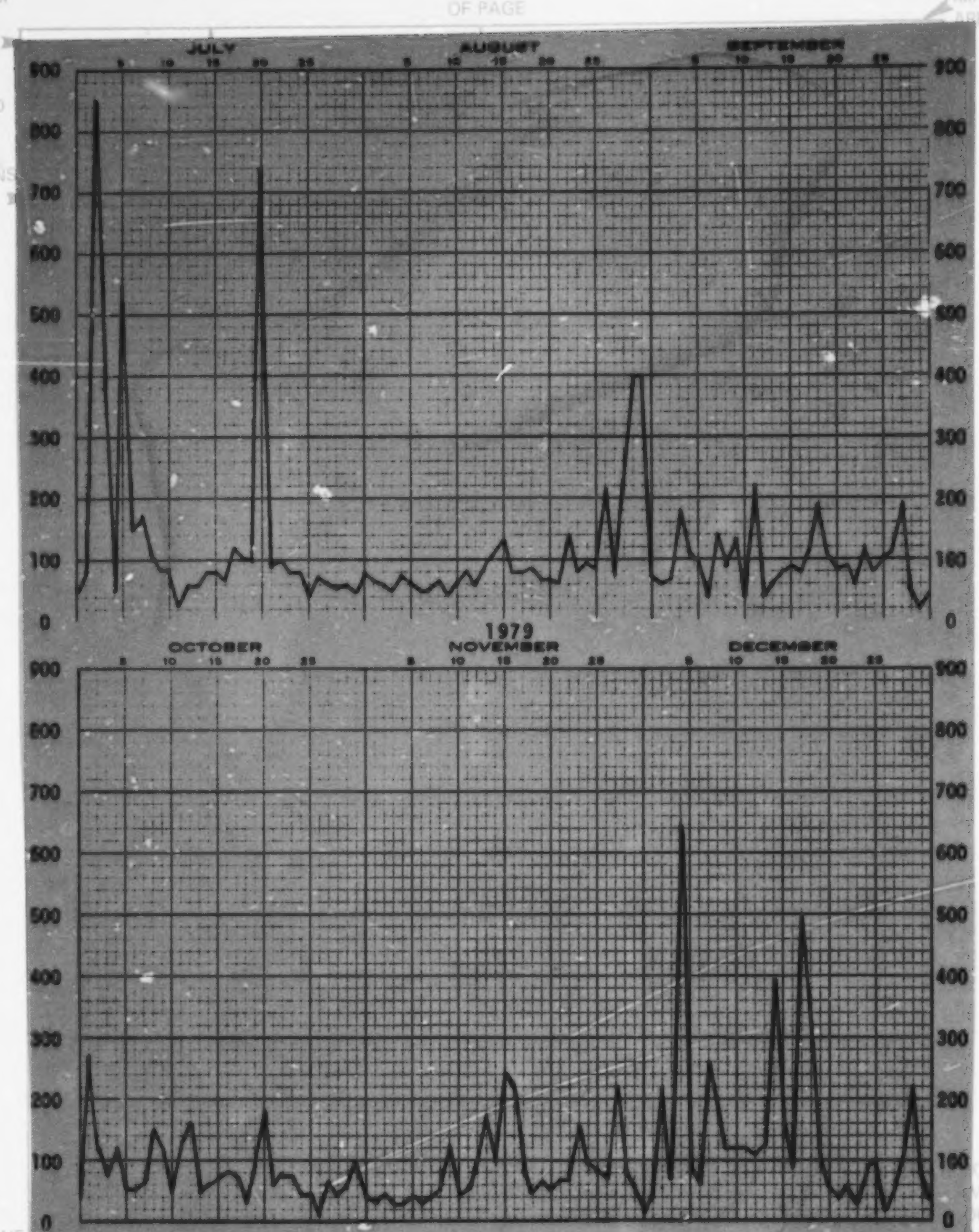

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Figure A-8. PACT process effluent TSS concentration, mg/liter.

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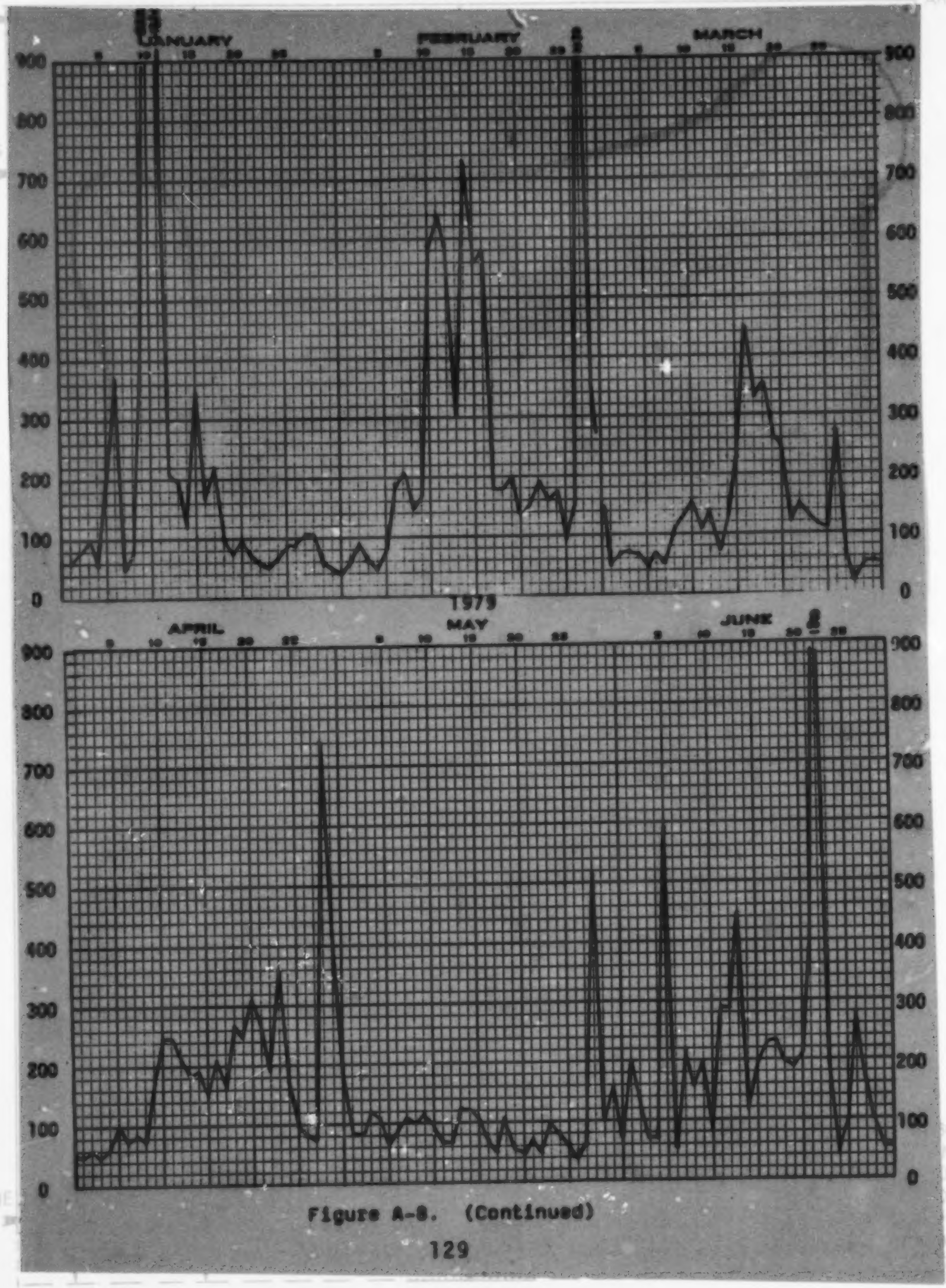

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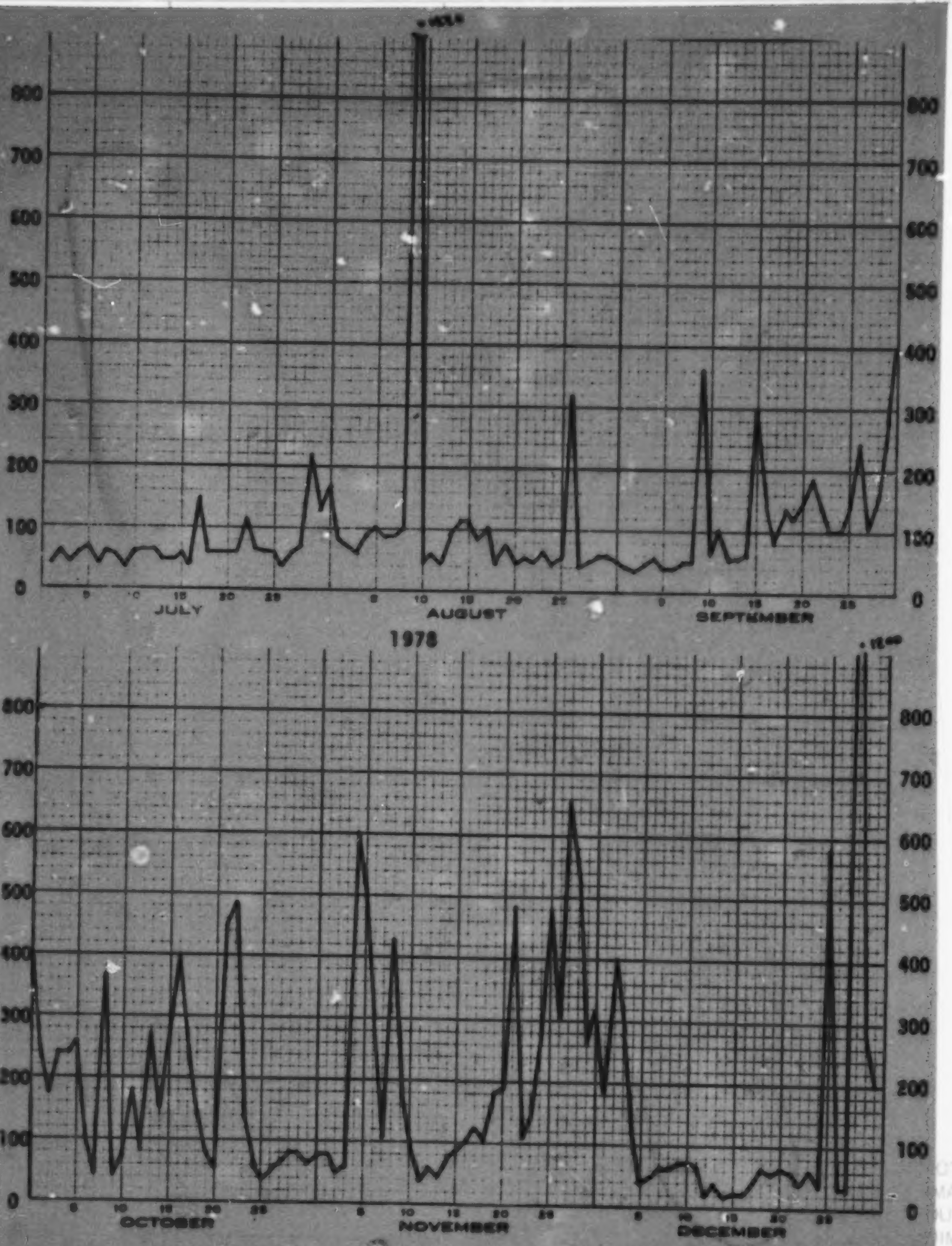

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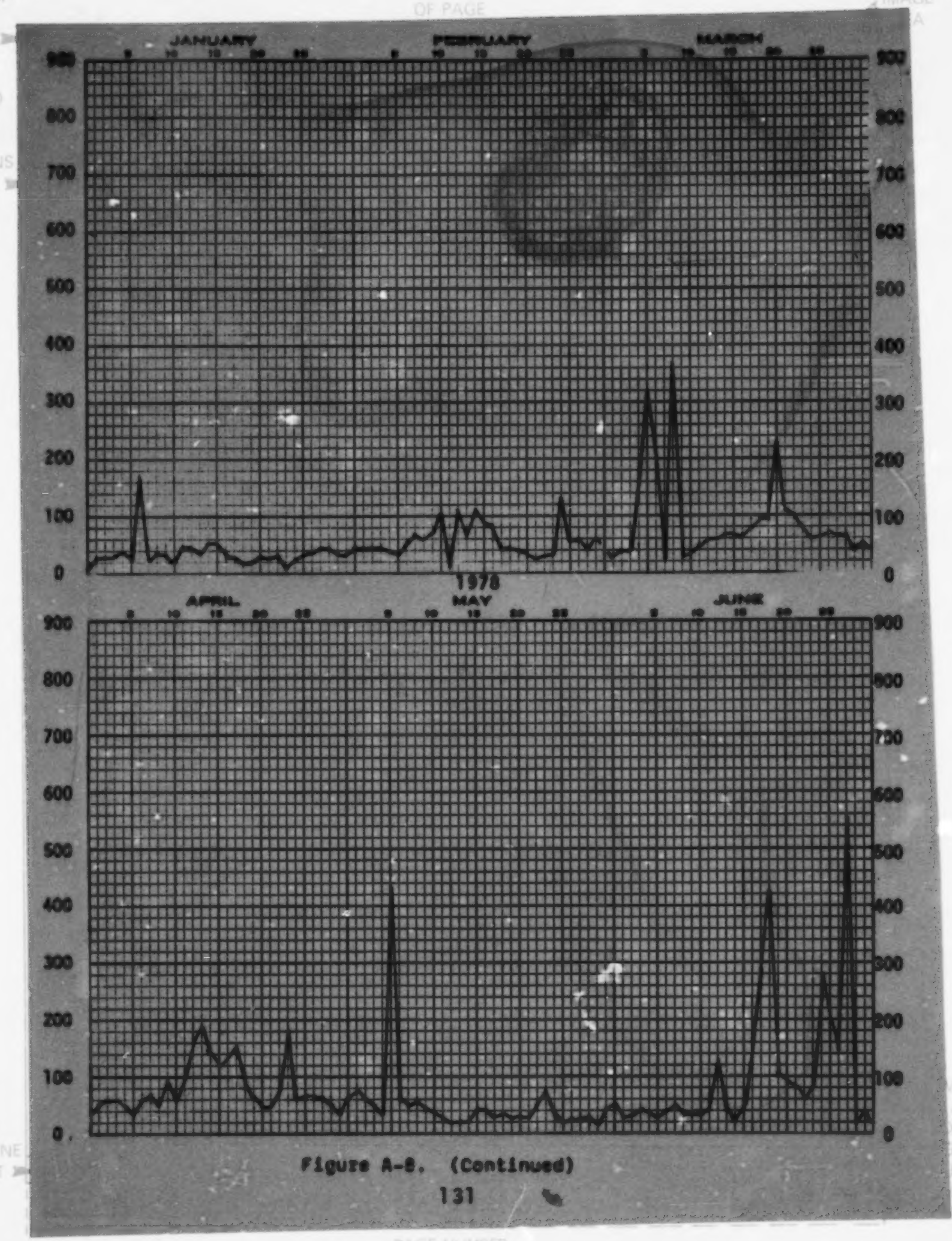

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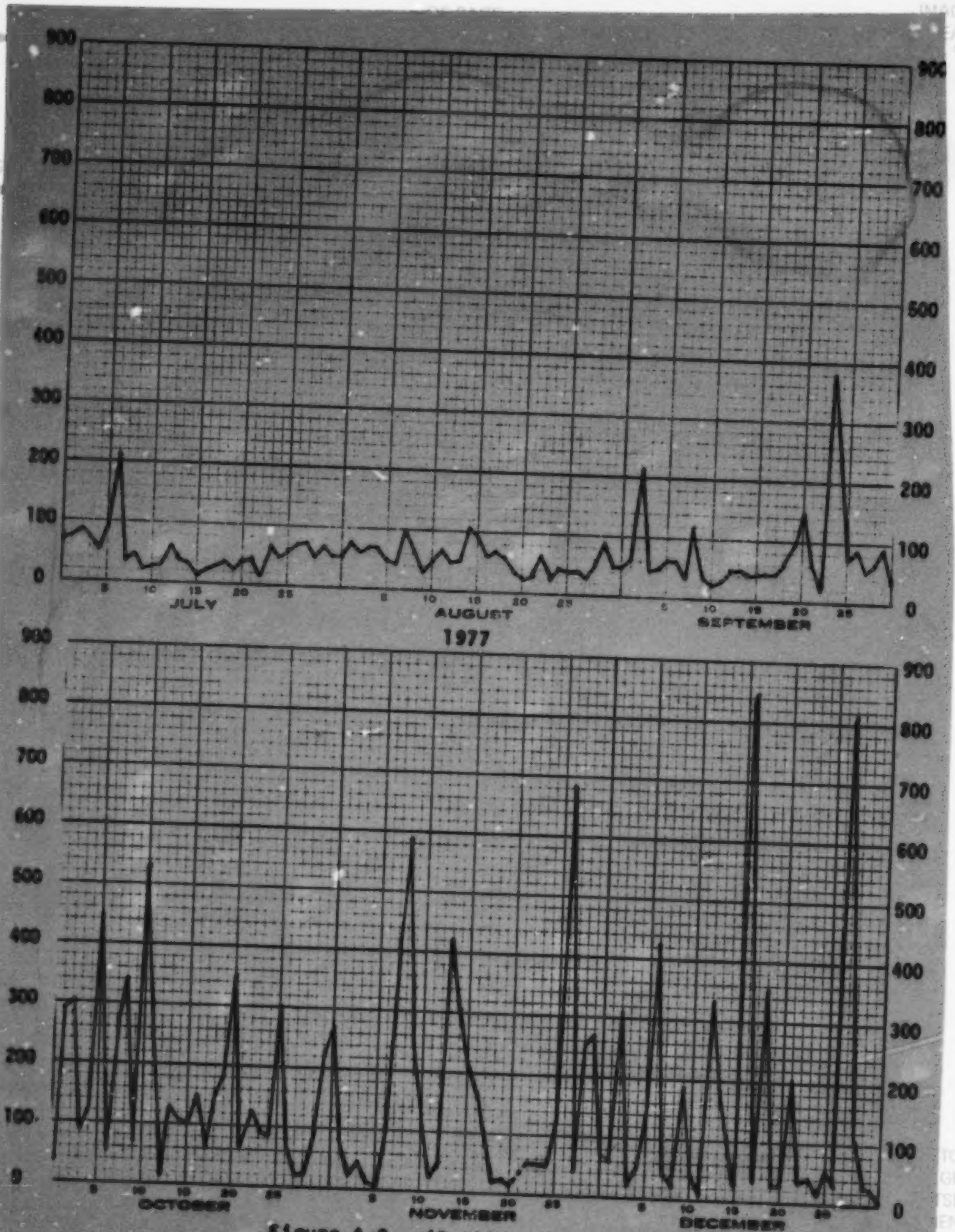

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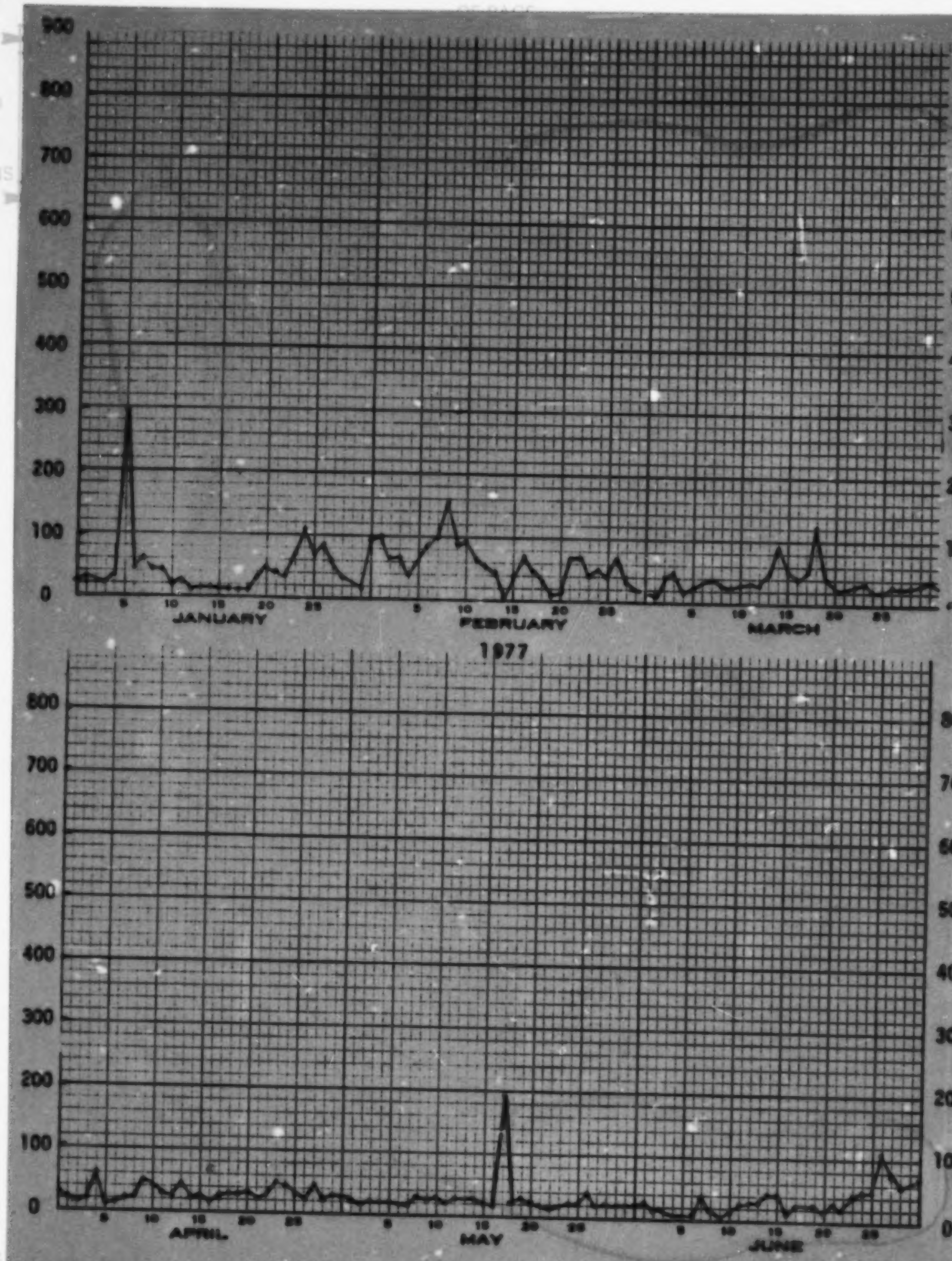

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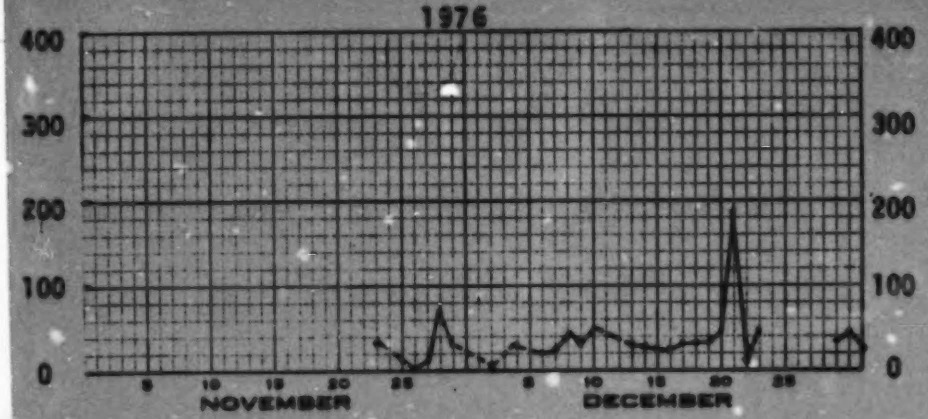

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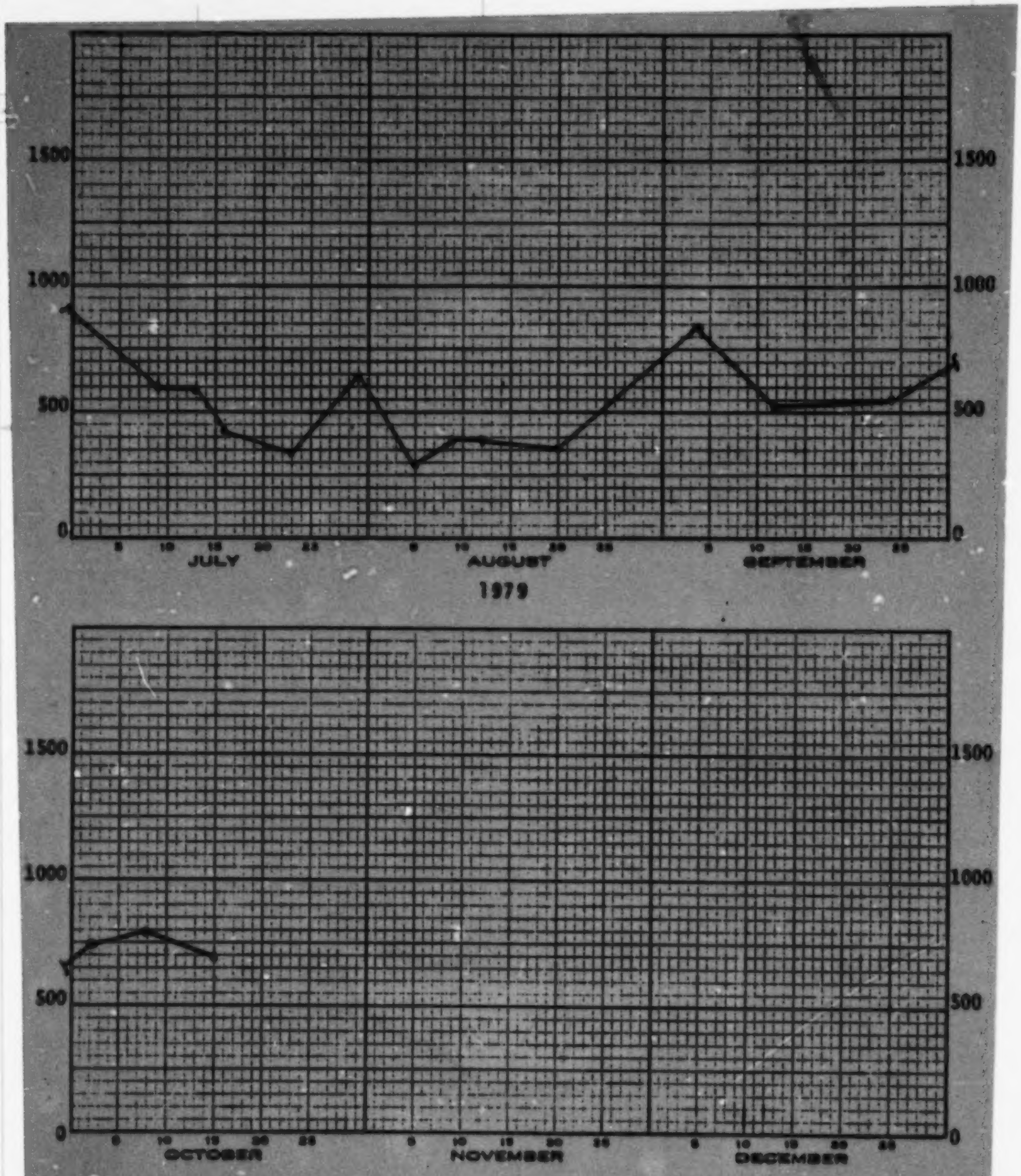

Figure A-9. Aerator ATP, ug/liter (ppb).

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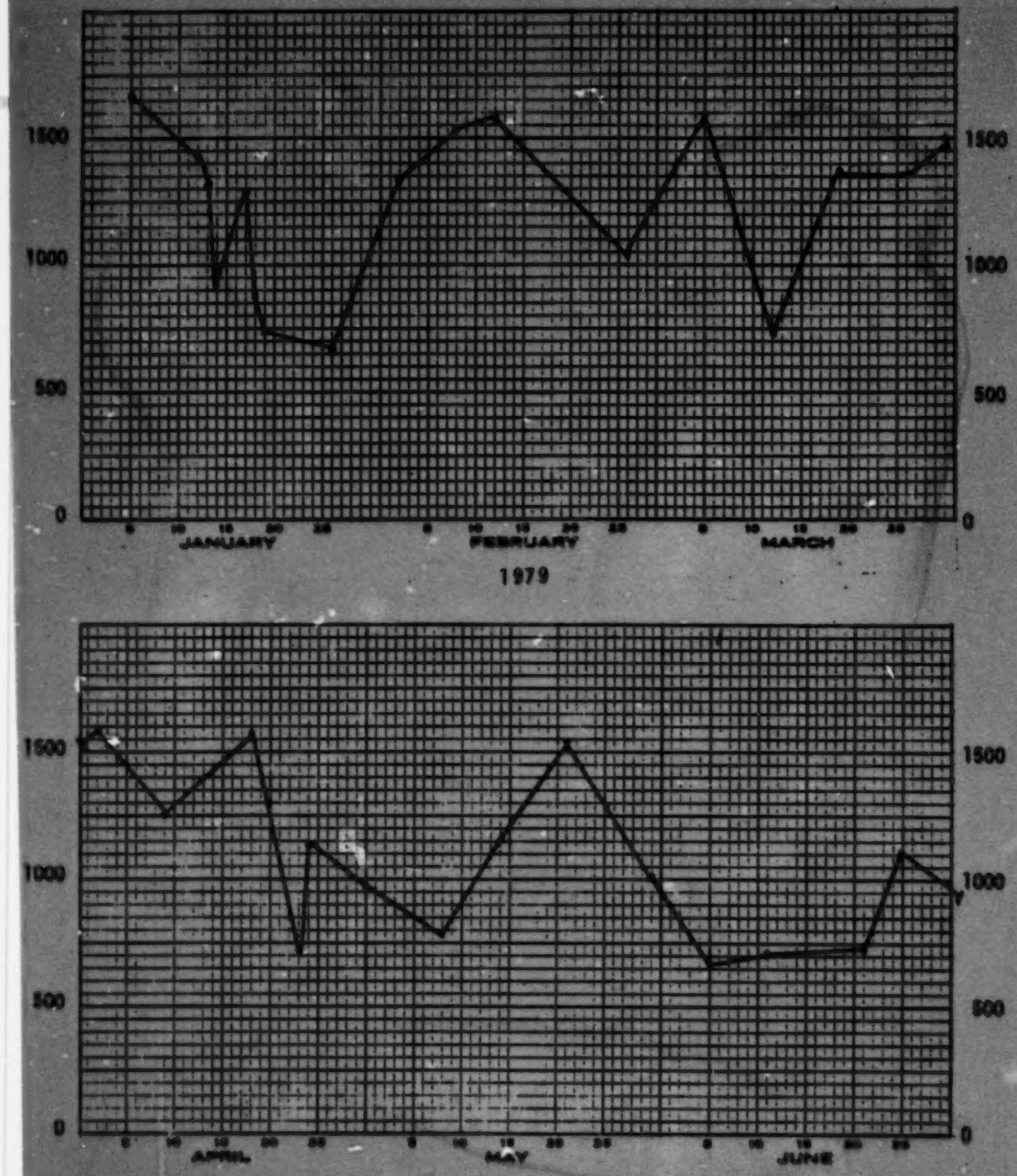

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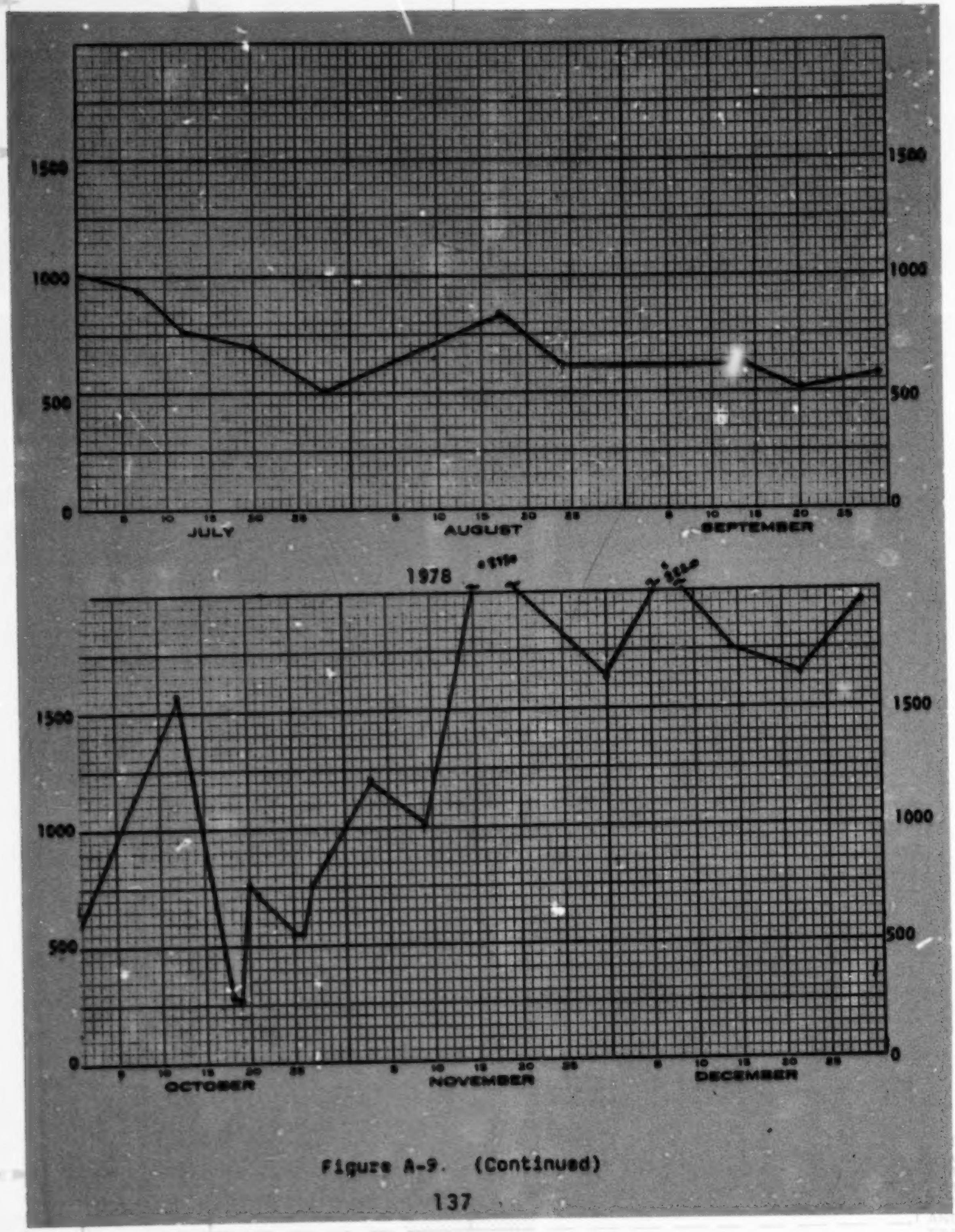

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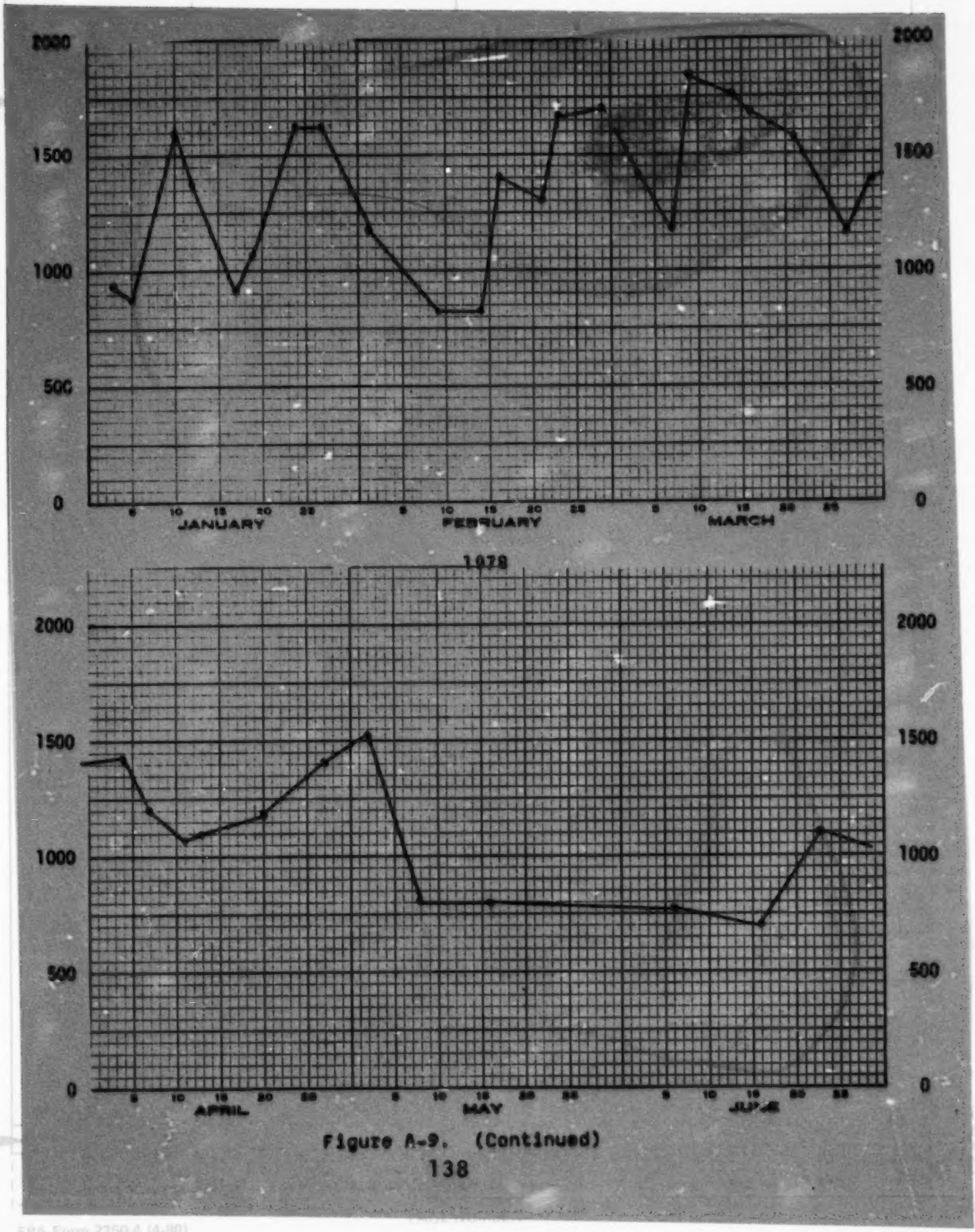

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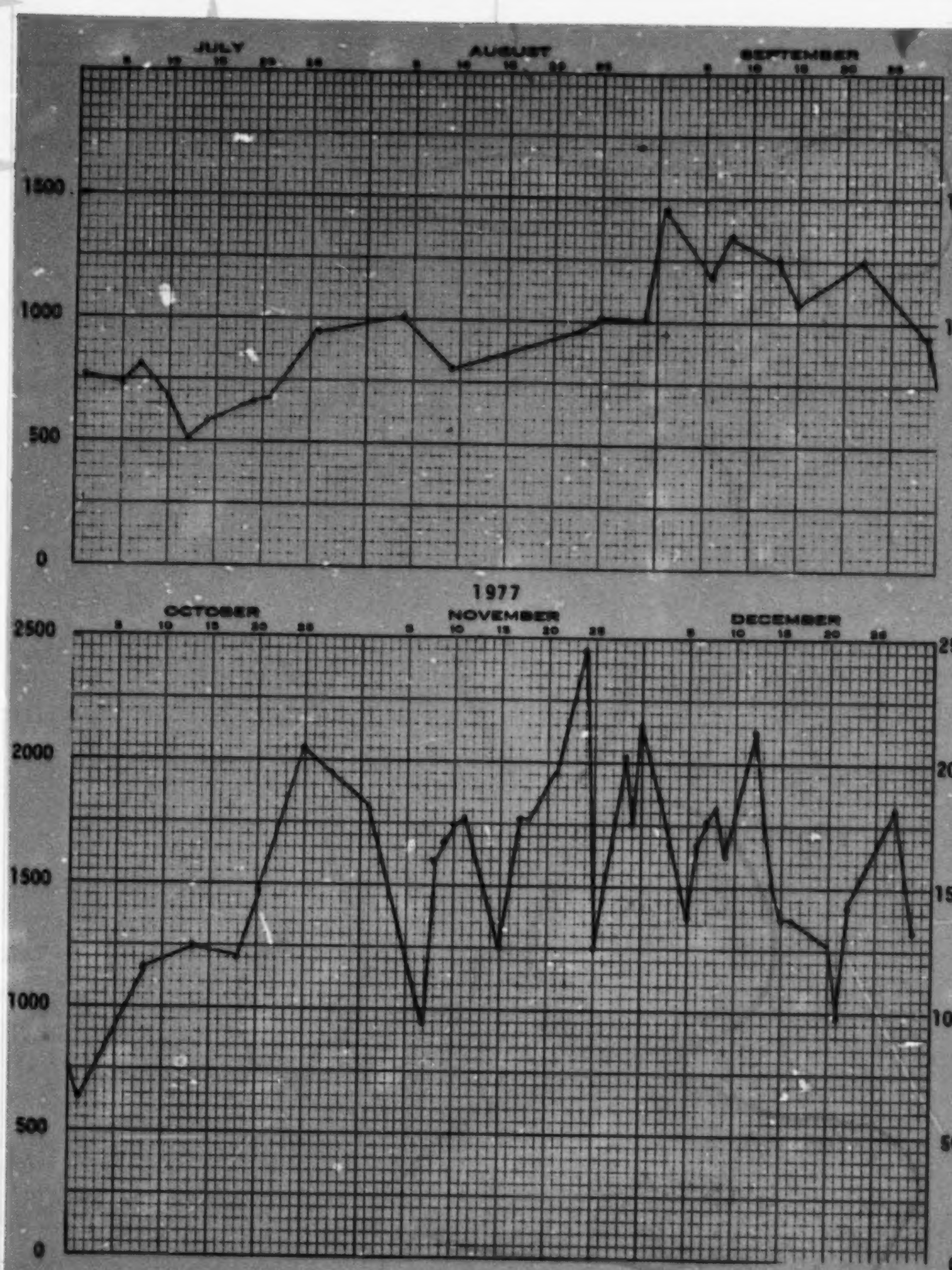

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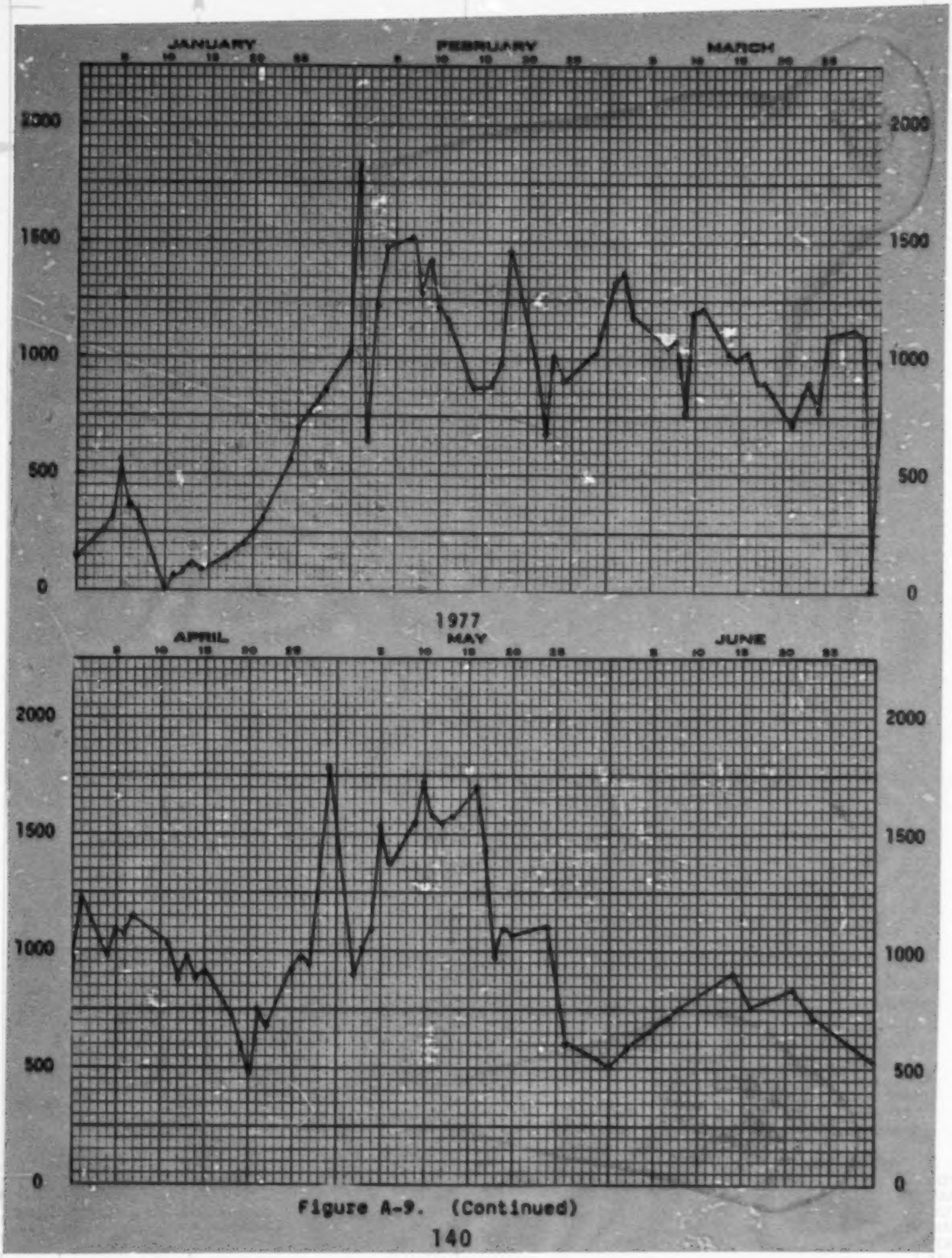

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TYPING GUIDE SHEET

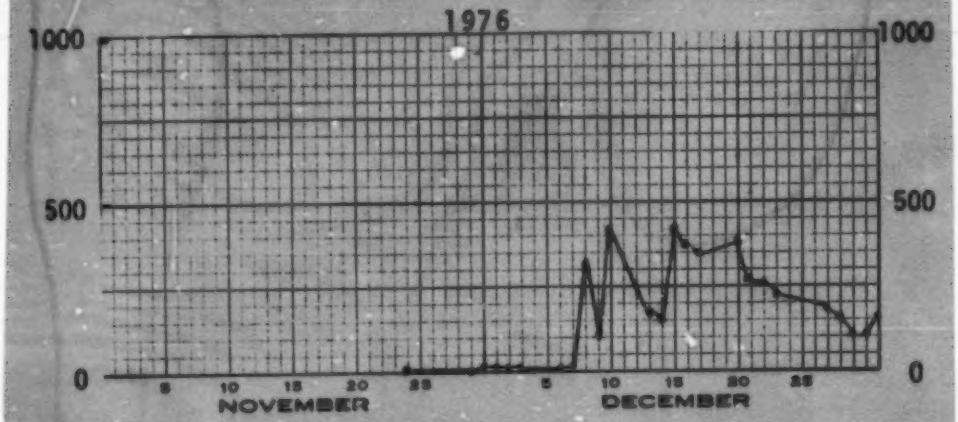

Figure A-9 (Continued)

TABLE A-1. PACT OPERATING DATA, LIQUID TRAIN - MONTHLY AVERAGES

	July '77	August '77	September '77	October '77
Feed				
Flow, m^3/min.	118	120	113	115
Sol. BOD_5. mg/liter	189	166 [21]	151 [51]	213 [41] ⑭
DOC, mg/liter	164 [28]	159 [28]	166 [33]	183 [24]
Color, APHA	1820 [660]	1600 [490]	1460 [630]	1290 [200]
TSS, mg/liter	25 [10]	33 [9]	31 [26]	30 [13]
Effluent				
Sol. BOD_5. mg/liter	17	8 [2]	8 [4]	6 [2] ⑱
% BOD Removal	91	95	95	97
DOC, mg/liter	51 [17]	31 [6]	35 [9]	33 [10]
% DOC Removal	68	81	79	82
Color, APHA	850 [230]	420	400	430
% Color Removal	53	74	73	67
TSS, mg/liter	73 [100]	59	71	165
Operating Conditions				
Carbon Dose, mg/liter	77	97	75	84
Nuchar SA, %	80	100	100	68
Hydrodarco, %	20	-	-	26
Regenerated, %	-	-	-	6
Aerators-MLSS, mg/liter	20,200	21,700	24,200	21,000
Aerators-Total Air flow, m^3/min.	1,180	1,390	1,530	1,430
Aerators-Sludge Age, days	36	41	37	27
Aerators-Daily Average Temp., °C	36.1	36	35.2	28.9
Aerators-Daily Average pH	6.6	6.7 (6.8-6.8)	6.8 (6.7-7.0)	6.8 (6.7-6.8)
Clarifier-CF-161 Underflow, m^3/min.	45.9	33.3	34.3	45.0
Clarifier-CF-162 Underflow, m^3/min.	34.4	26.4	37.5	43.9
Clarifiers-Recycle TSS, mg/liter	59,700	64,600	66,800	44,600
Solids Flux, kg/day/m^2	1,170	1,290	1,490	1,500
Days in Production Month	31	30	30	30

( ) = Range [ ] = Standard Deviation ⓝ = Number of data points if less than 20

(Continued)

TABLE A-1 (Continued)

Feed	November '77	December '77	January '78	February '78
Flow, m^3/min.	103	101	86.6	88.6
Sol. BOD_5. mg/liter	222 [51] ④	166 [89] ⑥	159 [62]	164 [74] ⑲
DOC, mg/liter	161 [25]	151 [20]	179 [21]	181 [26]
Color, APHA	990 [430]	1580 [430]	1170 [500]	1340 [500]
TSS, mg/liter	26 [18]	27	23	30 [12]
Effluent				
Sol. BOD_5. mg/liter	5 [3] ④	5.5 [2] ⑥	6 [4]	8 [7]
% BOD Removal	98	97	96	95
DOC, mg/liter	28 [5.1]	29 [8.0]	36 [12.7]	36 [9]
% DOC Removal	83	81	80	80
Color, APHA	340	620	380	435 [83]
% Color Removal	66	61	68	68
TSS, mg/liter	142 [149]	173 [203]	61 [135]	55 [27]
Operating Conditions				
Carbon Dose, mg/liter	116	136	142	127
Nuchar SA, %	47	64	80	62
Hydrodarco, %	42	35	20	27
Regenerated, %	11	1	-	11
Aerators-MLSS, mg/liter	21,200	21,600	20,700	22,600
Aerators-Total Air flow, m^3/min.	1,200	1,250	1,380	1,280
Aerators-Sludge Age, days	33	31	35	48
Aerators-Daily Average Temp., °C	24.3	19.1	16.9	16.6
Aerators-Daily Average pH	6.7 (6.6-6.8)	6.8 (6.7-6.8)	6.8 (6.7-6.8)	6.9 (6.7-7.2)
Clarifier-CF-161 Underflow, m^3/min.	46.4	47.1	44.9	46.4
Clarifier-CF-162 Underflow, m^3/min.	43.5	42.9	42.0	41.2
Clarifiers-Recycle TSS, mg/liter	43,200	44,800	41,200	46,000
Solids Flux, kg/day/m^2	1,370	1,320	1,170	1,350
Days in Production Month	30	30	34	28

( ) = Range [ ] = Standard Deviation ⓝ = Number of data points if less than 20

(Continued)

TABLE A-1 (Continued)

	March, '78	April, '78	May, '78	June, '78
Feed				
Flow, m^3/min.	88.6	89.3	86.9	93.7
Sol. BOD_5. mg/liter	163 [99] ⑱	194 [89] ⑭	181 [96]	171 [56] ⑲
DOC, mg/liter	205 [34]	193 [20]	192 [31]	174 [25]
Color, APHA	1670 [290]	1500 [430]	1530 [360]	1300 [400]
TSS, mg/liter	37 [22]	30 [8]	43 [36]	31 [19]
Effluent				
Sol. BOD_5. mg/liter	5 [5] ⑱	4 [3] ⑰	4.6 [2.7] ⑮	4.3 [2.5] ⑲
% BOD Removal	97	98	97	98
DOC, mg/liter	38 [8]	37 [6]	39 [11]	30 [6]
% DOC Removal	81	81	80	83
Color, APHA	500 [98]	380 [133]	600 [270]	460 [200]
% Color Removal	70	75	61	65
TSS, mg/liter	100 [86]	82 [32]	47 [15]	71 [85]
Operating Conditions				
Carbon Dose, mg/liter	144	131	156	107
Nuchar SA, %	36	31	55	32
Hydrodarco, %	14	14	4	29
Regenerated, %	50	55	41	39
Aerators-MLSS, mg/liter	24,200	27,600	27,200	25,300
Aerators-Total Air flow, m^3/min.	1,390	1,530	1,350	1,580
Aerators-Sludge Age, days	32	43	31	42
Aerators-Daily Average Temp., °C	18.8	24.2	27.2	32.5
Aerators-Daily Average pH	6.8 (6.6-7.0)	6.9 (6.7-7.3)	6.7 (6.5-6.9)	6.8 (6.4-7.0)
Clarifier-CF-161 Underflow, m^3/min.	47.3	45.0	48.1	27.4
Clarifier-CF-162 Underflow, m^3/min.	41.2	39.7	39.0	26.3
Clarifiers-Recycle TSS, mg/liter	48,600	57,000	54,700	74,600
Solids Flux, kg/day/m^2	1,420	1,600	1,570	1,250
Days in Production Month	29	32	29	30

( ) = Range [ ] = Standard Deviation ⓝ = Number of data points if less than 20

(Continued)

TABLE A-1 (Continued)

	July, '78	August, '78	September '78	October, '78
Feed				
Flow, m^3/min.	98.0	107	103	97.4
Sol. BOD_5. mg/liter	199 [99]	158 [29]	172 [40]	167 [45]
DOC, mg/liter	177 [33]	150 [25]	149 [21]	147 [25]
Color, APHA	1350 [350]	1360 [410]	1410 [370]	1450 [260]
TSS, mg/liter	36 [14]	48 [23]	42 [28]	79 [66]
Effluent				
Sol. BOD_5. mg/liter	3.2 [1.3]	6.7 [1.6]	6.4 [1.9]	7.5 [3.0]
% BOD Removal	98	96	96	96
DOC, mg/liter	28 [4.5]	31 [4.9]	26 [4.0]	30 [14.0]
% DOC Removal	84	79	82	80
Color, APHA	430 [140]	570 [170]	460 [130]	640 [320]
% Color Removal	68	58	67	56
TSS, mg/liter	89 [99]	122 [211]	100 [88]	154 [168]
Operating Conditions				
Carbon Dose, mg/liter	94	104	114	126
Nuchar SA, %	37	24	30	33
Hydrodarco, %	27	47	33	25
Regenerated, %	36	29	37	42
Aerators-MLSS, mg/liter	25,100	25,600	29,500	25,200
Aerators-Total Air flow, m^3/min.	1,310	1,250	1,350	1,280
Aerators-Sludge Age, days	60	39	54	31
Aerators-Daily Average Temp., °C	34.6	36.1	34.9	29.1
Aerators-Daily Average pH	6.7 (6.4-7.0)	6.5 (6.2-6.7)	6.7 (6.4-7.5)	6.7 (6.5-7.4)
Clarifier-CF-161 Underflow, m^3/min.	34.4	39.4	41.6	40.5
Clarifier-CF-162 Underflow, m^3/min.	33.8	38.6	41.6	41.6
Clarifiers-Recycle TSS, mg/liter	63,200	63,000	66,500	55,000
Solids Flux, kg/day/m^2	1,380	1,550	1,830	1,500
Days in Production Month	32	30	30	31

( ) = Range [ ] = Standard Deviation

(Continued)

TABLE A-1 (Continued)

	November, '78	December, '78	January, '79	February, '79
Feed				
Flow, m^3/min.	87.2	91.0	93.3	93.9
Sol. BOD$_5$. mg/liter	205 [72]	189 [39]	177 [37]	128 [46]
DOC, mg/liter	183 [22]	172 [26]	171 [29]	162 [20]
Color, APHA	1460 [430]	1700 [700]	1980 [1130]	1720 [540]
TSS, mg/liter	44 [16]	33 [16]	27 [8]	35 [8]
Effluent				
Sol. BOD$_5$. mg/liter	7 [9] ⑲	12 [6] ⑲	16 [12]	6.9 [4]
% BOD Removal	97	94	91	95
DOC, mg/liter	32 [4]	35 [8]	38 [21]	33 [9]
% DOC Removal	83	80	78	80
Color, APHA	490 [150]	380 [110]	470 [250]	610 [240]
% Color Removal	66	78	76	65
TSS, mg/liter	43 [61]	49 [51]	152 [265]	167 [186]
Operating Conditions				
Carbon Dose, mg/liter	150	124	129	143
Nuchar SA, %	69	55	76	64
Hydrodarco, %	5	17	22	30
Regenerated, %	26	28	2	6
Aerators-MLSS, mg/liter	26,000	25,800	21,000	18,100
Aerators-Total Air flow, m^3/min.	1,320	1,230	1,120	1,350
Aerators-Sludge Age, days	28	27	20	28
Aerators-Daily Average Temp., ^{o}C	25.8	19.7	16.4	15.5
Aerators-Daily Average pH	6.5 (6.3-6.8)	6.5 (6.3-6.7)	6.6 (6.4-6.8)	6.6 (6.2-6.8)
Clarifier-CF-161 Underflow, m^3/min.	40.1	40.5	31.4	18.5
Clarifier-CF-162 Underflow, m^3/min.	40.1	42.0	42.8	40.9
Clarifiers-Recycle TSS, mg/liter	55,500	55,500	47,200	48,300
Solids Flux, kg/day/m^2	1,450	1,480	1,170	910
Days in Production Month	29	30	33	30

( ) = Range   [ ] = Standard Deviation   ⓝ = Number of data points if less than 20

(Continued)

TABLE A-1 (Continued)

	March, '79	April, '79	May, '79	June, '79
Feed				
Flow, m^3/min.	97.2	90.6	87.0	98.4
Sol. BOD_5. mg/liter	151 [48]	174 [47]	227 [93]	141 [41]
DOC, mg/liter	169 [27]	192 [24]	178 [25]	156 [19]
Color, APHA	1940 [600]	2290 [650]	1430 [530]	1630 [480]
TSS, mg/liter	24 [9]	31 [11]	35 [8]	40 [13]
Effluent				
Sol. BOD_5. mg/liter	8.5 [12]	3.4 [2.6]	5.8 [4.4]	3.1 [3.5]
% BOD Removal	95	98	97	98
DOC, mg/liter	30 [6]	30 [6]	26 [4]	22 [5]
% DOC Removal	82	84	85	86
Color, APHA	310 [90]	620 [160]	300 [96]	450 [270]
% Color Removal	84	73	79	72
TSS, mg/liter	105 [106]	107 [63]	83 [90]	180 [240]
Operating Conditions				
Carbon Dose, mg/liter	146	148	119	103
Nuchar SA, %	52	49	34	32
Hydrodarco, %	8	7	6	13
Regenerated, %	40	44	60	55
Aerators-MLSS, mg/liter	17,900	23,900	24,200	25,500
Aerators-Total Air flow, m^3/min.	1,350	1,420	1,420	1,340
Aerators-Sludge Age, days	24	31	37	37
Aerators-Daily Average Temp., ^oC	18.7	24.5	29.4	32.0
Aerators-Daily Average pH	6.5 (6.0-7.0)	6.6 (6.4-6.9)	6.7 (6.4-6.9)	6.5 (6.2-6.7)
Clarifier-CF-161 Underflow, m^3/min.	19.3	20.9	37.0	59.4
Clarifier-CF-162 Underflow, m^3/min.	41.3	38.0	53.6	58.2
Clarifiers-Recycle TSS, mg/liter	46,900	57,600	60,700	54,200
Solids Flux, kg/day/m^2	920	1,060	1,200	1520
Days in Production Month	29	32	29	30

( ) = Range   [ ] = Standard Deviation

(Continued)

TABLE A-1 (Continued)

	July, '79	August, '79	September, '79	October, '79
Feed				
Flow, m^3/min.	103	104	104	100
Sol. BOD_5. mg/liter	128 [44]	200 [90]	149 [48]	123 [29]
DOC, mg/liter	144 [21]	154 [25]	177 [25]	162 [26]
Color, APHA	1560 [350]	1750 [380]	1700 [580]	840 [550]
TSS, mg/liter	40 [11]	30 [9]	32 [11]	33 [10]
Effluent				
Sol. BOD_5. mg/liter	3.0 [1.7]	6.1 [2.7]	3.7 [4]	2.2 [2]
% BOD Removal	98	98	98	98
DOC, mg/liter	21 [3]	25 [7]	29 [2.3]	25 [5]
% DOC Removal	85	84	83	85
Color, APHA	380 [120]	500 [150]	520 [150]	330 [170]
% Color Removal	76	71	69	61
TSS, mg/liter	163 [200]	72 [22]	131 [110]	92 [55]
Operating Conditions				
Carbon Dose, mg/liter	83	116	108	92
Nuchar SA, %	50	42	52	29
Hydrodarco, %	12	16	5	9
Regenerated, %	38	42	43	62
Aerators-MLSS, mg/liter	22,600	26,200	28,600	24,300
Aerators-Total Air flow, m^3/min.	1,310	1,340	1,370	1,370
Aerators-Sludge Age, days	29	54	47	45
Aerators-Daily Average Temp., ^oC	34.3	36.4	34.9	28.2
Aerators-Daily Average pH	6.4 (6.2-6.6)	6.5 (6.3-6.7)	6.5 (6.3-6.8)	6.7 (6.3-7.1)
Clarifier-CF-161 Underflow, m^3/min.	54.5	57.2	52.9	31.0
Clarifier-CF-162 Underflow, m^3/min.	58.0	58.7	58.6	33.1
Clarifiers-Recycle TSS, mg/liter	51,000	58,300	61,000	73,400
Solids Flux, kg/day/m^2	1,350	1,600	1,710	1150
Days in Production Month	32	29	30	31

( ) = Range [ ] = Standard Deviation

(Continued)

TABLE A-1 (Continued)

Feed	November, '79	December, '79
Flow, m^3/min.	88.7	84.8
Sol. BOD_5. mg/liter	145 [42]	225 [84]
DOC, mg/liter	150 [32]	175 [29]
Color, APHA	830 [280]	1770 [530]
TSS, mg/liter	37 [10]	30 [15]
Effluent		
Sol. BOD_5. mg/liter	7 [4]	18 [15]
% BOD Removal	95	92
DOC, mg/liter	31 [7]	41 [8]
% DOC Removal	79	77
Color, APHA	390 [210]	800 [330]
% Color Removal	53	51
TSS, mg/liter	80 [53]	155 [153]
Operating Conditions		
Carbon Dose, mg/liter	91	114
Nuchar SA, %	20	67
Hydrodarco, %	20	10
Regenerated, %	60	23
Aerators-MLSS, mg/liter	23,300	22,750
Aerators-Total Air flow, m^3/min.	1,420	1,438
Aerators-Sludge Age, days	34	33
Aerators-Daily Average Temp., ^oC	24.0	21.3
Aerators-Daily Average pH	6.7 (6.2-7.2)	6.7 (6.3-7.3)
Clarifier-CF-161 Underflow, m^3/min.	29.0	33.2
Clarifier-CF-162 Underflow, m^3/min.	29.4	33.7
Clarifiers-Recycle TSS, mg/liter	69,900	58,800
Solids Flux, kg/day/m^2	990	970
Days in Production Month	29	35

( ) = Range   [ ] = Standard Deviation

TABLE A-2. PACT OPERATING DATA, SOLIDS TRAIN - MONTHLY AVERAGES

	Feb. '78	March '78	April '78	May '78
Filtration				
Cycles/day, FP-277	4.5	7.9	7.2	7.8
Total Cycles	162(2)	242(2)	231	227
Filter Cake Solids, %	43	44	45	45
Solids Filtered, Dry kg.	386,000	613,000	600,000	585,000
Carbon Regeneration				
Furnace Feed, % In Time	48	79	73	66
Dry Solids Fed, kg.	273,000	602,000	591,000	487,000
Regenerated Carbon Made, kg.	74,500	278,000	286,000	201,000
Regenerated Carbon IN	522	487	516	476
Regenerated Carbon Ash, %	19.7	15.4	15.5	15.6
Regenerated Carbon Volatiles, %	8.6	7.2	8.2	7.1
Wet Sludge Feed Rate(1), kg/hr.	1,860	2,440	2,306	2,350
Days in Production Month	28	29	32	29

(1) While feeding.

(2) Includes cycles on swing press FP-76

(Continued)

TABLE A-2 (Continued)

	June '78	July '78	Aug. '78	Sept. '78
Filtration				
Cycles/day, FP-277	5.9	3.0	3.8	3.8
Total Cycles	176	97	115	115
Filter Cake Solids, %	48	45	47	45
Solids Filtered, Dry kg.	475,000	249,000	308,000	300,000
Carbon Regeneration				
Furnace Feed, % In Time	72	49	58	65
Dry Solids Fed, kg.	530,000	306,000	317,000	395,000
Regenerated Carbon Made, kg.	176,000	157,000	134,000	204,000
Regenerated Carbon IN	560	421	390	455
Regenerated Carbon Ash, %	17.2	27.2	30.2	21.2
Regenerated Carbon Volatiles, %	8.0	11.8	12.0	9.8
Wet Sludge Feed Rate(1), kg/hr.	2,070	1,860	1,640	1,840
Days in Production Month	30	32	30	30

(1) While feeding.

(Continued)

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EPA-287 (Cin.)
(4-76)

TABLE A-2 (Continued)

	Oct. '78	Nov. '78	Dec. '78	Jan. '79
Filtration				
Cycles/day, FP-277	5.4	4.1	6.2	3.5
Total Cycles	167	119	187	122(2)
Filter Cake Solids, %	46	48	45	No Data
Solids Filtered, Dry kg.	438,000	318,000	469,000	313,000
Carbon Regeneration				
Furnace Feed, % In Time	54	38	37	7
Dry Solids Fed, kg.	445,000	301,000	208,000	38,000
Regenerated Carbon Made, kg.	220,000	149,000	113,000	11,000
Regenerated Carbon IN	415	448	438	No Data
Regenerated Carbon Ash, %	30.2	15.9	18.1	No Data
Regenerated Carbon Volatiles, %	8.7	8.1	8.9	No Data
Wet Sludge Feed Rate(1), kg/hr.	2,330	2,400	1,770	1,540
Days in Production Month	31	29	30	33

(1) While feeding.

(2) Includes cycles on swing press FP-76

(Continued)

TABLE A-2 (Continued)

	Feb. '79	March '79	April '79	May '79
Filtration				
Cycles/day, FP-277	1.8	7.0	6.6	6.8
Total Cycles	54	202	210	197
Filter Cake Solids, %	44	45	45	45
Solids Filtered, Dry kg.	137,000	515,000	550,000	514,000
Carbon Regeneration				
Furnace Feed, % In Time	23	81	81	76
Dry Solids Fed, kg.	132,000	537,000	648,000	593,000
Regenerated Carbon Made, kg.	55,000	235,000	286,000	266,000
Regenerated Carbon IN	No Data	494	462	537
Regenerated Carbon Ash, %	No Data	13.5	13.9	11.2
Regenerated Carbon Volatiles, %	No Data	8.4	8.7	8.4
Wet Sludge Feed Rate(1), kg/hr.	1,760	2,100	2,260	2,460
Days in Production Month	30	29	32	29

(1) While feeding.

(Continued)

EPA-287 (Cin.)
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TABLE A-2 (Continued)

	June '79	July '79	Aug. '79	Sept. '79
Filtration				
Cycles/day, FP-277	1.8	4.3	4.1	2.9
Total Cycles	55	139	119	88
Filter Cake Solids, %	44	46	46	46
Solids Filtered, Dry kg.	140,000	360,000	316,000	230,000
Carbon Regeneration				
Furnace Feed, % In Time	69	47	66	53
Dry Solids Fed, kg.	416,000	352,000	521,000	386,000
Regenerated Carbon Made, kg.	209,000	157,000	226,000	200,000
Regenerated Carbon IN	537	429	454	479
Regenerated Carbon Ash, %	16.7	19.0	21.2	18.5
Regenerated Carbon Volatiles, %	8.6	9.1	7.9	7.9
Wet Sludge Feed Rate(1), kg/hr.	1,940	2,130	2,430	2,210
Days in Production Month	30	32	29	30

(1) While feeding.

(Continued)

EPA-287 (Cin.) (4-76)

TABLE A-2 (Continued)

	Oct. '79	Nov. '79	Dec. '79
Filtration			
Cycles/day, FP-277	4.3	4.0	2.1
Total Cycles	134	235(2)	200(2)
Filter Cake Solids, %	45	43	41
Solids Filtered, Dry kg.	345,000	585,000	465,000
Carbon Regeneration			
Furnace Feed, % In Time	78	87	33
Dry Solids Fed, kg.	417,000	423,000	152,000
Regenerated Carbon Made, kg.	251,000	208,000	60,000
Regenerated Carbon IN	478	432	393
Regenerated Carbon Ash, %	20.3	24.2	29.3
Regenerated Carbon Volatiles, %	7.3	7.0	8.7
Wet Sludge Feed Rate(1), kg/hr.	1,630	1,640	1,480
Days in Production Month	31	29	35

(1) While feeding.

(2) Includes cycles on swing press FP-76